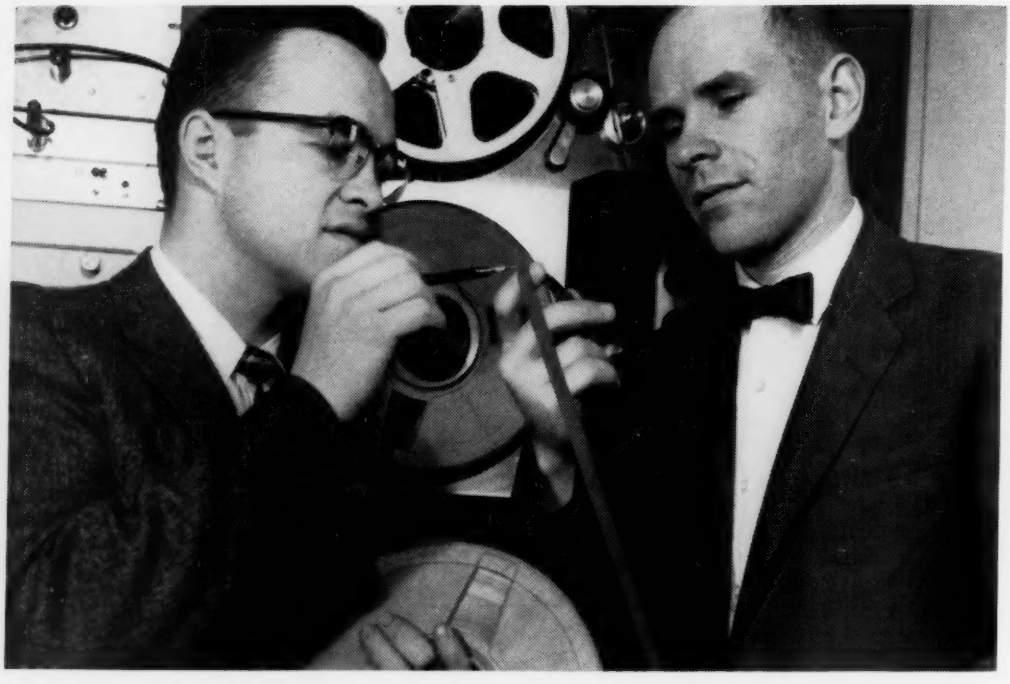
The SCIENTIFIC MONTHLY

UNIV OF M ITY GAN
AUG 2 1957
ENGINEERING LIBRARY

VOL. 84 NO. 6 JUNE 1957



Bell Laboratories researchers Henry S. McDonald, Dr. Eng. from Johns Hopkins, and Max V. Mathews, Sc.D. from M.I.T., examine magnetic tape used in new research technique. Voice waves are converted into sequences of numbers by periodic sampling of amplitudes, 8000 samples per second. General purpose electronic computers act on these numbers as a proposed transmitting device might.

They send real voices on imaginary journeys

In their quest for better telephone service, Bell Laboratories researchers must explore many new devices proposed for the transmission of speech signals. For example, apparatus can be made to transmit speech in the form of pulses. But researchers must always answer the crucial question: how would a voice sent through a proposed device sound to the listener?

In the past it often has been necessary to construct costly apparatus to find out. Now the researchers have devised a way to make a high-speed electronic computer perfectly imitate the behavior of the device, no matter how complicated the device may be.

The answer is obtained without building any apparatus at all.

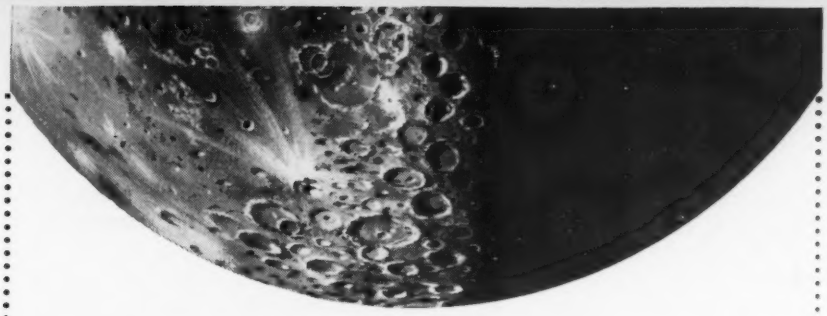
The researchers set up a "program" to be followed by the computer. Actual voice waves are converted into a sequence of numbers by sampling the waves 8000 times per second. Numbers and program are then fed into the computer which performs the calculations and "writes out" a new sequence of numbers. This new sequence is converted back into real speech. Listeners hear exactly how well the non-existent device could transmit a real voice.

With this novel technique, new transmission ideas are screened in only a fraction of the time formerly required. Thus valuable time and scientific manpower are saved in Bell Laboratories' constant search to provide still better service for telephone customers.

BELL TELEPHONE LABORATORIES

World center of communications research and development

UNI ITY
OF M GAN
AUG 1357
ENGINEERING
LIBRARY



To that rare breed of men who can
"see" the shape of things to come:

We can use your ideas in Large Rocket Engineering

We have a small but heavyweight group here at Rocketdyne known as the Preliminary Analysis & Design Section.

These are our idea men. It's their job to see the Big Picture... to approach outer-space projects without earthbound prejudice ...to anticipate problems and sense the likeliest ways to solve them. They are qualified experts in a broad range of fields. Some have extraordinary imaginations; others are brilliant analysts; but all share the ability to hit the highlights without becoming enmeshed in the details. In short, they are scientific skirmishers who scout each new challenge—then summon research and development specialists to meet it.

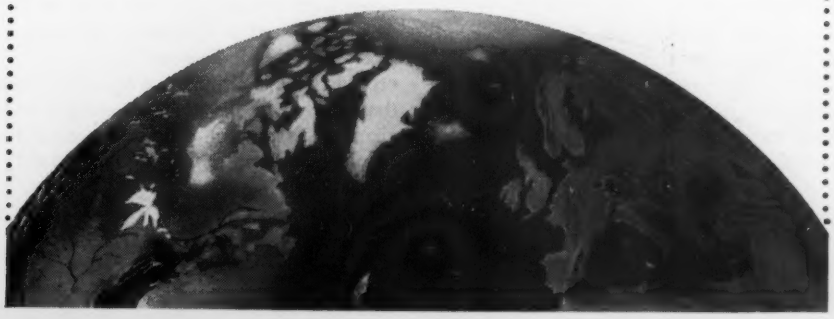
If this sounds like *your* kind of group, you may be the very man we're seeking for one of the several jobs now available. We can't describe them in detail here, but they include *Controls, New Concepts* (nuclear and ion applications), *Preliminary Design, Fluid Mechanics, Heat Transfer, Engine & Missile Systems,* and *Military Operations Analysis.*

We can use men with advanced degrees and solid experience in control systems and power-plant design. If you are a young engineer or physicist with an M.S. or Ph.D. and an analytical turn of mind, we can offer on-the-job training in many pioneering fields where experience is practically nonexistent.

Please tell us about yourself—what you've done... what you'd like to do. Write: A. W. Jamieson, Rocketdyne Engineering Personnel Dept. SM-6, 6633 Canoga Ave., Canoga Park, California.

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.

BUILDERS OF POWER FOR OUTER SPACE



Science and Technology

All inquiries concerning items listed here should be addressed to The Scientific Monthly, *Room 740, 11 W. 42 St., New York 36, N.Y. Include the name(s) of the manufacturer(s) and the department number(s).*

Infrared Spectrometer

Designed to fit on the laboratory bench, an infrared spectrometer was specifically developed for analytic and organic chemists. The instrument scans the range from 2 to 16 μ in 16 min, recording linearly in transmittance and wavelength. The record is traced by a flat-bed recorder on preprinted charts. Controls are limited to start-stop buttons, a selector switch, and zero and 100-percent adjustment knobs. A variety of accessories are available, including devices for sampling of solids, liquids, and gases, for microsamples, and for reflectance. (Beckman Instruments, Inc., Dept. M250)

Biological Stains and Indicators

A new 66-page catalog lists biological stains and indicators. Prices are also given. Accompanying the catalog is a reprint entitled, "Some aspects of biological staining." (Allied Chemical and Dye Corp., Dept. M236)

Nitrogen Cryostats

Infrared detectors can be cooled to approximately −196°C with nitrogen cryostats. Model 147 cryostat consists of a miniature cooling head and a compressor-regulator assembly. The Joule-Thompson effect and regenerative cooling are used. Compressed nitrogen is passed through a miniature heat exchanger where it is cooled by nitrogen returning from an expansion nozzle. The cryostat is available with a variety of cooling heads. Heat-pumping capacities range from 1.5 to 5 watts. (Perkin-Elmer Corp., Dept. M228)

Boron-10

Boron-10 is now available from the Atomic Energy Commission for general use. About 20 lb/wk are being produced. Boron-10, an efficient absorber of thermal neutrons, is used in reactor control rods and in instruments for radiation detection. (Hooker Electrochemical Co., Dept. M242)

Literature on Polarography

Bibliography of polarographic literature covers the period from 1922 to 1955. Publications are listed in alphabetical order by author and chronologically under each author. The items are numbered for access via a detailed subject index. The bibliography cites 6815 references. (E. H. Sargent and Co., Dept. M258)

Crystal-Lattice Models

Models of basic lattices, elements, inorganic compounds, organic compounds, and alloys are scaled to 1 A = 25 mm. The designs are based on x-ray and electron-diffraction data. Wooden spheres representing the atoms are colored to identify the atom and are joined by metal rods. (Arthur S. LaPine and Co., Dept. M278)

Balance

Microbalance operates by balancing the sample weight against a torque generated by an electric current in a magnetic field. Weight is read on a multiturn dial. Four ranges, from 0-to-5 mg to 0-to-50 mg, provide sensitivities of 1 μg to 8 μg. Precision is 0.02 percent and accuracy is 0.05 percent of full scale on all ranges. (Cahn Instrument Co., Dept. M253)

Microscope

Reflecting microscope manufactured by R. and J. Beck, Ltd., of London, England, uses reflecting optics to avoid chromatic aberration. The range of wavelengths that can be employed is limited only by the reflectivity of the mirrors. With the aluminum reflecting surfaces, the range extends well into both the infrared and ultraviolet regions. A range of objectives is available having nominal magnifications from 15 to 172. A second objective is used as condenser when nonvisible illumination is used. An eyepiece of the inclined type is used to observe the specimen for focusing. A movable reflector permits removal of the eyepiece from the light path; this allows the light to pass to a camera. The camera uses 35-mm film and takes up to 40 pictures 1 in. in diameter. (Ealing Corp., Dept. M230)

Vacuum Valve

Designed for use at pressures 10^{-10} mm-Hg and lower, a vacuum valve has an effective conductance for nitrogen of 1×10^{-11} lit/sec. The valve can be baked at temperatures up to 450°C. The valve assembly consists of a Monel cup sealed off by a flexible Monel diaphragm. Closure is effected by metal-to-metal contact between a nose piece carried by the diaphragm and a 0.25-in. orifice. (Consolidated Electrodynamics Corp., Dept. M345)

Pressure-Transducer System

Instead of measuring charge, which is proportional to pressure, a pressure-transducer system measures current, which is proportional to rate of change of pressure. Pressure is sensed by a quartz piezoelectric element. Response time is said to be 15 sec. Ranges from 0-to-1 to 0-to-1000 lb/in.^{2} are provided. (Kistler Instrument Co., Dept. M303)

Radiation Monitor

Five-channel radiation monitor indicates radiation levels at five separate locations. Each channel is provided with a Geiger-Müller tube or a scintillation detector mounted at a distance of up to several thousand feet from the indicators. Indication of count rate is provided for each channel by contact-type meter relays that may also be used to actuate alarms. The five-channel instrument can be mounted in a 19-in. rack. (Universal Atomics Corp., Dept. M302)

THE SCIENTIFIC MONTHLY

VOL. 84 JUNE 1957 NO. 6

Index Issue

Oil Shale and Bituminous Sand . . . . . *F. L. Hartley* and *C. S. Brinegar* 275

Nautical Charting (1807–1957) . . . . . *A. L. Shalowitz* 290

Sinkholes, Bottomless Lakes, and the Pecos River . . . . . *E. R. Harrington* 302

Some Implications of the Study of Animal Behavior . . . . . *W. H. Thorpe* 309

Book Reviews of *World Symposium on Applied Solar Energy, Proceedings; Aspects of Culture; The Great Chain of Life; An Encyclopaedia of the Iron and Steel Industry; The Galathea Deep Sea Expedition 1950–1952; Discussions on Child Development; Advances in Electronics and Electron Physics; The Wind and the Weather*; Books Reviewed in *Science*; New Books 320

Cover: Closeup of a Piece of Colorado Oil Shale

[*Courtesy F. L. Hartley and C. S. Brinegar, Union Oil Company of California, see page 275*]

GRAHAM DUSHANE, *Editor*

CHARLOTTE V. MEETING, *Associate Editor*

JOSEPH TURNER, *Assistant Editor*

EDITORIAL BOARD

WALLACE R. BRODE
BENTLEY GLASS
KARL LARK-HOROVITZ
EDWIN M. LERNER
WILLIAM L. STRAUS, JR.
EDWARD L. TATUM

Advertising Representative: EARL J. SCHERAGO

THE SCIENTIFIC MONTHLY, established in 1872 as *The Popular Science Monthly*, has been an official publication of the American Association for the Advancement of Science since 1915. It is published for the Association at Business Press, Inc., Lancaster, Pa.

Copyright, 1957, by the American Association for the Advancement of Science. Entered at the Lancaster, Pa., Post Office as second class matter under the act of March 3, 1879.

All correspondence should be addressed to THE SCIENTIFIC MONTHLY, 1515 Massachusetts Ave., N.W., Washington 5, D. C. Manuscripts should be typed with double spacing and submitted in duplicate. The AAAS assumes no responsibility for the safety of manuscripts and photographs or for the statements and opinions expressed by contributors.

Change of address: Four weeks are required to effect a change of address. If possible, please furnish an address stencil label from a recent issue. Be sure to give both old and new addresses, including postal zone numbers, if any.

Annual subscriptions: $7.50, domestic and foreign. Single copies, 75¢. Special rates to members of the AAAS.

THE SCIENTIFIC MONTHLY is indexed in the *Reader's Guide to Periodical Literature*.

The AAAS also publishes SCIENCE. Subscription and advertising rates will be furnished on request.

Research and development at the Lockheed Missile Systems Division Research Laboratory in Palo Alto is of a most advanced nature. Particular areas of interest include microwaves, telemetering, radar, guidance, reliability, data processing, electronic systems, instrumentation, servomechanisms. Inquiries are invited from those qualified by ability and experience for exploratory efforts of utmost importance.

Here members of the Electronics Division discuss systems radar problems related to measurement of missile trajectories. Left to right: K. T. Larkin, radar and command guidance; Dr. S. B. Batdorf, head of the Electronics Division; Dr. H. N. Leifer (standing), solid state; Dr. R. J. Burke, telemetering; S. Janken, product engineering.

Lockheed

MISSILE SYSTEMS DIVISION

research and development staff

LOCKHEED AIRCRAFT CORPORATION

PALO ALTO • SUNNYVALE • VAN NUYS

CALIFORNIA

THE
SCIENTIFIC MONTHLY

JUNE 1957

Oil Shale and Bituminous Sand

FRED L. HARTLEY and CLAUDE S. BRINEGAR

Mr. Hartley is vice president for research of the Union Oil Company of California and is located at Union Oil's Research Center, 30 miles southeast of Los Angeles. He joined the Union Oil Company in 1939 as an engineering trainee, shortly after his graduation from the University of British Columbia with a degree in chemical engineering. He served as manufacturing process supervisor and general superintendent at Union's Los Angeles refinery before transferring to the research department to head the commercial development division. In 1955 he was made department general manager and in 1956 was elected vice president. Mr. Hartley has directed Union Oil Company's comprehensive oil shale research and development program since its inception at the beginning of 1955. In the summer of 1955, he spent 7 weeks in Europe, studying, at firsthand, oil shale experiments and operations in Germany, Scotland, and Sweden. Dr. Brinegar is supervisor of economics and planning for the Union Oil Company. He received his academic training at Stanford University, where he took a Ph.D. degree in economic research, an M.S. degree in mathematical statistics, and a B.A. degree in economics. He has been on the research staff of the Food Research Institute at Stanford University, has been retained as economic consultant to the Emporium-Capwell Corporation, and has taught in the extension divisions of the University of California (Los Angeles) and Whittier College. This article is based on a talk given at the Energy Resources Conference in Denver, Colorado, 30 October 1956.

THE beginning of the modern petroleum age can be traced to the world's first oil well, which was drilled in 1859 by Edwin Drake, near Titusville, Pennsylvania. Moving forward from that single well, we have become, in less than a century, a world that almost literally revolves on oil. In the United States today, for example, crude oil and natural gas provide 65 percent of all the energy that 168 million Americans derive from mineral fuels and water power. And if current trends persist, the figure may soon pass 70 percent.

The world-wide importance of oil does not have to be stressed. What should be emphasized, however, is the *quantity* of oil that we have needed to reach our present industrialization and high standard of living. Those who keep track of such things tell us that, since the first well was drilled in 1859, the United States has produced and consumed more than 55 *billion* (10^9) barrels of oil. For the world, the total is more than 95 billion barrels.

But crude oil is not our subject here. Instead, we wish to discuss two other sources of oil—or, more accurately, two other sources of hydrocarbon liquids—that contain known reserves many times 95 billion barrels. The deposits of these two resources scattered throughout the world have been given a variety of names. We have designated them by the two terms that seem to have the most widespread acceptance, *oil shale* and *bituminous sand*.

Although these two resources have been virtually bypassed thus far by the petroleum age, an inventory of the world's remaining liquid fuels forces us to conclude that, almost certainly, they cannot be bypassed much longer. This view has been strengthened quite recently by several careful studies made by eminent geologists and other energy

specialists who have generally concluded that crude oil will inevitably, within a relatively few years, fall short of the world's requirements. In particular, there is growing opinion—which is discussed in more detail subsequently—that crude oil production in the United States will reach its peak in the next 10 to 20 years and decline slowly thereafter. If this occurs, then it seems inevitable that energy costs will increase to the point where the most favorably situated bituminous sands and the richest oil shales will become competitive with crude oil.

The governments of Canada and the United States are sponsoring research work to aid in developing the technology needed to extract oil from these two sources. In addition, several private oil companies have done, or are doing, research on the various problems of oil shale and bituminous sand processing. The Union Oil Company of California is currently involved in the most extensive oil shale research program yet undertaken by private industry. This research work is discussed in detail in later sections.

Oil Shale

The Bureau of Mines defines "oil shale" as a laminated, sedimentary rock—that is, a rock formed by excessive geologic deposits of clay, mud, and other sediment—containing organic material (usually called "kerogen") from which appreciable amounts of oil can be obtained by the application of heat (*1*). The important point is that oil shale does not contain oil, as such. The oil is formed by thermal decomposition of the solid organic material that is derived from preexistent plant and animal life. To further complicate matters, the geologists tell us that, technically, oil shale is not a shale but, rather, a "marlstone," a limestone with a mixture of minerals. Thus, strictly speaking, what we call "oil shale" is not a shale and it does not contain any oil. Geologically, the origin of oil shale is obscure. The general belief seems to be that it was formed during millions of years of successive deposits of plant and animal life, mixed with sand and clay, at the bottoms of quiet lakes and lagoons (*2*).

There is likewise disagreement on the relationship between the origins of oil shale and crude oil. Although there is fairly general agreement that crude oil was formed as a by-product of the decomposition of plant and animal remains deposited in muds and other sediments, the geologists do not agree on why one organic deposit eventually became a liquid (crude oil) and the other remained a solid (oil shale). Certainly, differences of temperature and pressure associated with differing locations had some effects. One of the popular views is that oil shale represents simply an "incomplete" crude oil field. A colorful statement of this theory was made by R. D. George, Colorado State geologist for many years, when he described an oil shale deposit this way: "As nature left this oil undistilled and the oil field unfinished, man must supplant her work before he can obtain the oil. This may be done by heating the shales in retorts" (*3*). Other geologists, however, feel that no one theory that has yet been proposed is entirely consistent with all the observable facts.

In the oil shale deposits it is the relationship between organic matter and mineral matter that determines how much oil can be obtained. At one extreme we have the deposits, very rich in organic matter, which are borderline between coal and oil shale. These include the "torbanites" of Scotland, Australia, and elsewhere and the "cannel" and "Boghead" coals found in small deposits in many places in the world. These deposits, which might be called "ultrarich oil shales," often yield considerably more than 100 gallons of oil per ton. They are relatively scarce, however, and consequently are of little world-wide importance. At the other extreme we have the lean shales that yield less than 15 gallons per ton. These lean deposits, which are found scattered throughout the world, are especially prevalent in the western United States. Since the cost of recovering oil from such lean deposits is extremely high, we currently exclude them from any inventory of available oil shale reserves.

Between these extremes we find some truly enormous deposits. Although an exact tabulation is impossible because of the lack of adequate geologic studies, a brief summary of what we do know might serve to place oil shale in better perspective. We classify the countries that have oil shale deposits in two major groups: (i) the countries with deposits that are known to be relatively small, or those whose deposits are virtually unexplored, and (ii) the countries with deposits large enough to be of world-wide significance.

The first group includes Estonia, Sweden, Scotland, Germany, the U.S.S.R., Spain, Italy, and France. These European countries have had, or have at present, small commercial operations. However, since none has substantial reserves, the total contribution that oil shale makes to Europe's oil supply will remain slight. This first group also includes these non-European countries: Manchuria, Australia, the Union of South Africa, Canada, and Burma. In the 1930's, Manchuria had the world's largest oil shale plant (nearly 10,000 tons per day), but we do not know whether or not this still operates. South Africa has a small, modern plant that produces less than 1000 barrels per day. Its dis-

Oil shale cliffs near Grand Valley, Colorado, from a picture taken about 1918.

tance from other oil sources has enabled it to operate profitably. Australia's very rich deposit was mined intermittently before World War II, although no shale oil is produced there at this time. Canada and Burma have oil shale deposits of as yet undetermined significance. We have learned, however, that a Canadian company (the Nashwaak Corporation, located in Montreal) plans to start construction of an oil shale plant next spring at New Brunswick. It will use the oil shale as a low-cost fuel to manufacture power. We can only guess at the total potential production of these small oil shale deposits. If we assume that the fragmentary information is roughly accurate, it seems unlikely that all of these countries together contain more than 5 billion barrels of recoverable shale oil. The European countries probably contain about half of the total.

The second group, countries with deposits large enough to be of world-wide significance, includes only two: Brazil and the United States. Although it is known, for certain, that vast oil shale deposits occur in many sections of Brazil, we have, unfortunately, only very meager information about their richness or extent. Ayres and Scarlott (*4*) have placed Brazil's total recoverable shale oil reserve at the enormous figure of 300 billion barrels. Although other estimates are much more conservative, we can be sure that many billions of barrels of oil are available. The most extensive deposit, known as the Iraty black shale, is said to be at least 250 miles long, with a bed depth of from 100 to 300 feet. The Government of Brazil has sponsored research in oil shale retorting for several years. Since Brazil is an advancing nation that lacks adequate fuel supplies, we can be sure that the Brazilians will continue to search for a means of utilizing this energy reserve.

Let us turn, finally, to the United States. It has been reported by the U.S. Geological Survey that oil shale has been found in Alaska and in at least half of the states (*5*). There are two deposits of greatest significance: (i) Lower-grade (and geologically older) black shales, known as the Chattanooga formation, occur in several eastern states. Since these black shales are usually found in thin

seams that yield less than 15 gallons per ton, they are not as yet counted in our oil shale inventory. They do, however, represent a several-billion-barrel reserve for use sometime in the distant future. (ii) Rich and thick oil shales, known as the Green River formation, occur in the Rocky Mountain region. It is the Green River formation that is of greatest economic importance. The portion of this deposit that is found in the northwest corner of Colorado in what is called the Piceance Creek Basin contains thick, rich oil shale beds that can be mined from large, mechanized, underground mines. The latest geologic studies, which are discussed subsequently, place the total oil shale deposit in this small basin at nearly 1 *trillion* barrels. It is here that the United States' oil shale industry will ultimately develop.

Thus, a survey of the world's known oil shale deposits makes it evident that the United States and Brazil are the two countries of foremost importance in the oil shale picture. Since Brazil's deposits are relatively unexplored, our primary attention must be focused on the reserves of Green River formation found in adjoining sections of Colorado, Utah, and Wyoming.

Green River Formation

The Green River formation covers an area of approximately 16,500 square miles—2600 in Colorado, 4700 in Utah, and 9200 in Wyoming. Little is known about either the richness or the extent of the Utah and Wyoming shale. The limited amount of assay work that has been done in these two states suggests that the Utah deposit may contain perhaps 50 billion barrels of shale oil and the Wyoming deposit possibly 10 percent as much (*6*).

As we just mentioned, it is the portion of the Green River formation occurring in Colorado's Piceance Creek Basin that is of greatest economic interest (Fig. 1). This basin, which has been the scene of most private shale land purchases, contains deposits that vary in thickness from 200 to 2000 feet. (Some of the thickest beds can be seen in the exposed cliff faces along U.S. Highway 24, in the Rifle-Grand Valley area.) Core holes drilled through the deposit have shown that it has an average depth of about 1300 feet of shale that assays greater than 15 gallons per ton and, more important, several smaller strata that assay in excess of 30 gallons per ton. The most recent estimate of the oil contained in this basin was made in February 1956 by J. R. Donnell of the U.S. Geological Survey. He reported, at the meeting of the Colorado Mining Association, that cuttings from oil wells drilled in the basin had shown that the shale beds are much deeper than had been previously believed. Taking this new information into account, he then recalculated the total for deposits that yield at least 15 gallons per ton. His answer was the astronomical figure of 960 billion barrels. He has since advised us that this number is "conservative."

Of more immediate interest to the oil industry, however, is the rich substrata known as the "mahogany ledge." (The freshly mined shale has a distinct mahogany color.) The mahogany ledge, which lies under a layer of overburden that averages about 1000 feet in depth, is from 70 to 90 feet thick. Although a few seams assay as much as 70 gallons per ton, the average for the full deposit is about 30 gallons (*6*). Donnell's new calculations placed the total mahogany ledge reserve at 90 billion barrels.

Let us pause for a minute and try to grasp the significance of these multibillion-barrel figures. It seems to us that, to place them in proper perspective, one must grasp the following five fundamental points.

1) There are *classes* of oil shale reserves. Although the terms are arbitrary, we have found the following classification to be helpful: "Total reserve" means the total amount of oil physically contained in the deposit; "total recoverable reserve" means the total amount of oil that can be recovered by known or prospective commercial methods; and, finally, "total economic reserve" means the total amount of oil that can be recovered at costs that are roughly competitive with current or prospective industry costs for crude oil.

2) The oil industry, of necessity, must limit its interest to recoverable and economic reserves. Although the Piceance Creek Basin as a whole may contain 960 billion barrels of shale oil, the mining specialists tell us that at present we can afford to mine only the mahogany ledge strata by methods that will recover about 75 percent of the deposit. Thus, the mahogany ledge's *recoverable* reserve is about 65 to 70 billion barrels.

3) Just as the recoverable reserve will increase with improved technology, the economic reserve will increase as crude oil costs rise. Although we are unable to estimate today's economic reserve accurately, we do know that it is somewhat less than the recoverable reserve. About half of the mahogany ledge is owned by private companies and half by the United States Government. The Government has assigned about 5 percent of the total area to the Navy as a petroleum reserve, and the remainder has been withdrawn from entry, either by claim or lease. Thus, as a rough estimate, we can guess that the economic reserve available

to private industry at present and prospective costs is about 30 to 40 billion barrels.

4) A 30- to 40-billion barrel economic reserve can support a very large oil shale industry. For example, at a production level of 1 million barrels a day—this is approximately California's current total oil production—this reserve would last for 80 years. And after 80 years it is almost certain that improved technology and rising crude oil costs will have added additional oil shale to the economic reserve. It is also probable that the Government will have opened its now-closed acreage for private purchase or lease.

5) Since the United States is presently consuming an average of 9.3 million barrels of crude oil each day, and since the rate is growing, year by year, it seems unlikely that Colorado's oil shale deposits will ever be limited in their development by market demand. Rather, the limiting factors would seem to be the accessibility of deposits and working space.

Oil Shale Technology

Now that we have an idea of the *quantity* of oil shale available to an American industry, we turn next to the subject of technology. First, however, a few comments are in order on the industries that exist today in Scotland and Sweden.

Scotland has been producing oil from oil shale continuously since 1850. In recent years, however, production—currently under 3000 barrels per day—has been declining. Unfortunately, in Scotland, oil shale occurs in deposits that are only a few feet thick. Consequently the Scots have been unable to adapt large-scale mechanization to their mining operations, with the result that, as the richer deposits are exhausted, mining costs have risen rapidly. British Petroleum, the owner of the Scottish shale company, indicated in its 1955 annual report that the operation is now unprofitable and that it is endeavoring to move the employees to other jobs. We interpret this to mean that it intends to close down its shale plants.

Sweden has an oil shale industry that was designed and built at government expense during World War II. The plant was enlarged at the end of the war and, today, produces a wide range of finished petroleum and chemical products from shale oil production of about 3000 barrels per day. Sweden is fortunate in that its shale deposits are close enough to the surface so that, after removal of a few feet of dirt, the oil shale can be mined directly, without expensive underground tunnels, equipment, and the like.

Since these two companies represent almost the sum total of demonstrated oil shale technology, Union Oil representatives studied their operations last year. This study confirmed what many of us have suspected: different shale deposits generally require different production methods. We are able to profit from the experience in material-handling and in by-product processing and disposal of these two companies. But as for basic technology, we were forced to conclude that Colorado's oil shale could not be economically processed by European methods. It was evident that new large-scale retorting and refining methods are needed if shale oil is to compete with North America's crude oil.

With this fact in mind, we now return to the problem of processing Colorado's shale deposits. Here is what we know of applicable technology concerning mining, retorting, and refining.

The Synthetic Liquid Fuels Act, passed by Congress in 1944, directed the Bureau of Mines to conduct research and development work on methods of producing commercial oil products from oil shale and coal. One of the most important phases of this work was a large-scale experimental mine located in the mahogany ledge, near Rifle, Colorado. The mahogany ledge has physical characteristics that make it unusually favorable to low-cost underground mining. The formation is flat, horizontal, and strong. Thus, it is possible to open

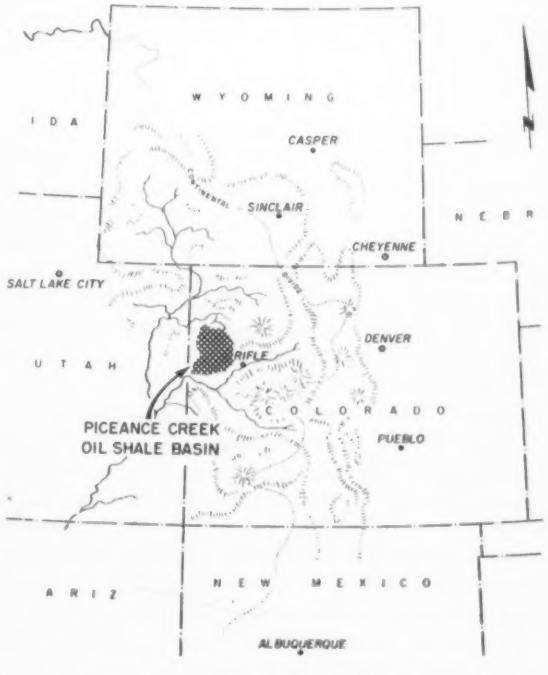
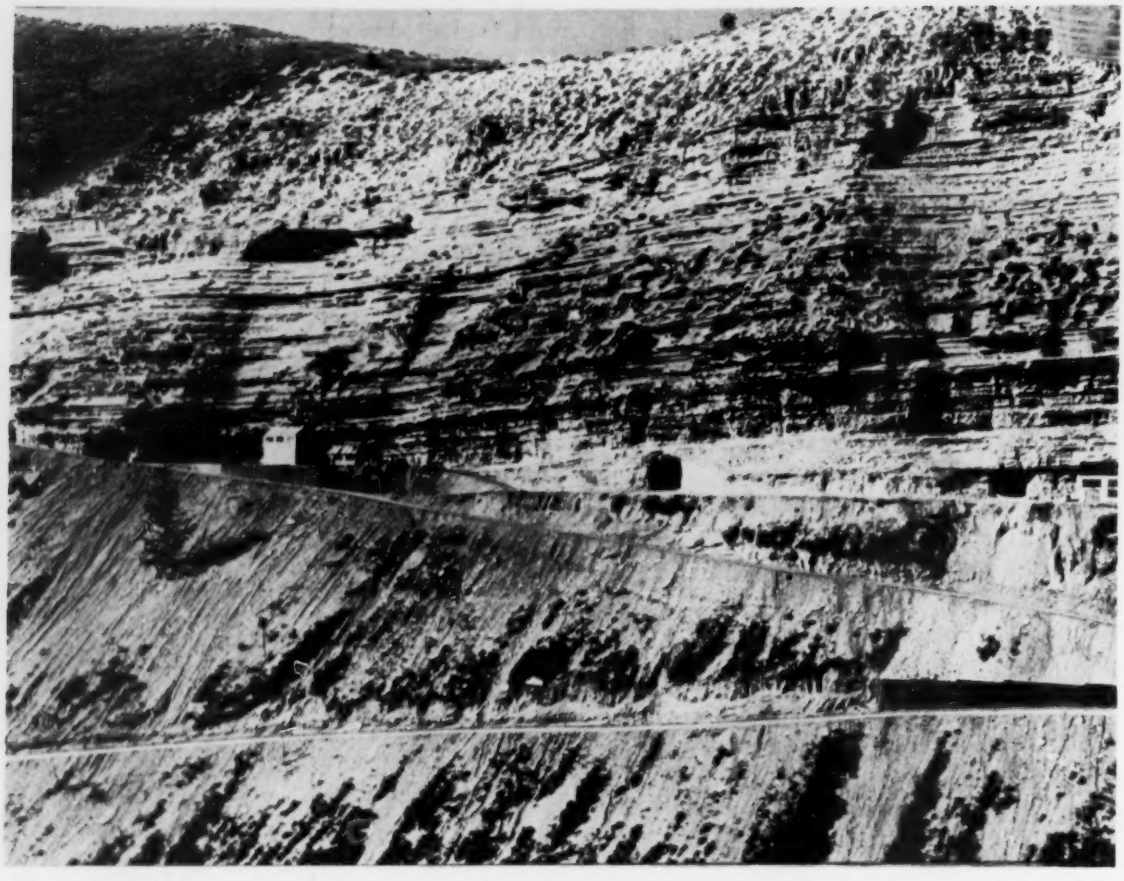


Fig. 1. Piceance Creek oil shale basin in the Rocky Mountain states.



Aerial view of U.S. Bureau of Mines' experimental oil shale mines in cliffs near Rifle, Colorado. [Courtesy U.S. Bureau of Mines]

large room-and-pillar mines without using costly artificial roof supports. The bureau has demonstrated the success of a two-bench system advancing into the 70-foot mahogany ledge face. The roof is supported by pillars of oil shale, 60 feet square, left standing at staggered intervals of 60 feet. The roof is further supported by several hundred "roof bolts," 6 feet long and 1 inch in diameter, which act as "staples," binding the layers of rock together. This room-and-pillar mining method recovers 75 percent of the available mahogany ledge shale.

With the use of a combination of well-known and specially designed mining equipment, the bureau demonstrated that large quantities of oil shale could be mined, crushed, and delivered for retorting at costs of between $0.50 and $0.60 a ton. This was an outstanding accomplishment, and the Bureau of Mines should be particularly proud of it. Prior to their work, it was generally believed that underground mining costs would be twice as high as this—certainly high enough to keep oil shale noncompetitive for many, many years.

However, on 28 February 1955, a serious roof fall occurred quite unexpectedly at the bureau's mine. A full report on the fall has not been made public, but the bureau did intimate that it invalidated much of their work and that further experimental tests were necessary before the method could be termed "a commercial success." Because of Union Oil's vital interest in oil shale, we have consulted with mining experts on this problem. The general belief seems to be that, with appropriate modifications, the mining method *is* safe and reliable. This belief is supported by current experience in the limestone industry, where large room-and-pillar mines patterned after the bureau's design are being used with outstanding success. We should also add that our confidence in the mining method is shared by Cameron and Jones, former Bureau of Mines' engineers and now engineering consultants who specialize in oil-shale development work (*7*).

After oil shale is mined and crushed to manageable size, we move to the step where, by the application of heat in excess of about 700°F, the organic

"kerogen" is converted to a liquid oil. This step is called "retorting." If we were to express the whole of oil shale technology by an equation, we would be forced to assign our largest x to retorting. This, truly, is the biggest unknown.

A recent survey by the Bureau of Mines disclosed that by 1945 there were more than 2000 patents that related to oil shale retorts (*8*). And the patent bulletins show that the ideas continue to spew forth. Unfortunately, very few of the ideas ever go beyond the drawing boards, and even fewer reach the working-model stage. For the retorting facts of life are simply this: to develop a successful, economic retort for Colorado oil shale takes more than inventive genius, more than years of mechanical "know-how," and more than the patience of Job; it also takes many millions of dollars.

A study of Colorado's oil shale and of the oil economy that shale oil must be a part of makes it evident that the successful retort has to meet four minimum conditions (*9*): (i) It must be durable, dependable, and capable of high throughput at a very low cost. Since shale oil production must be on a large enough scale to have nation-wide significance, the retort must be suitable to mass operation in large groups. (ii) Since the retorting of oil shale forms oil, gas, and a residue of fixed carbon, and since the oil is a relatively small part of the total (10 to 15 percent by weight), the successful retort must obtain most of its energy from either the gas or the fixed carbon, or from both. (iii) Since water is a scarce commodity in Colorado, the successful retorting process must operate without process water or must certainly use only a very small quantity. (iv) The retort must produce an ash that can be stored in the open without danger of polluting either the atmosphere or the water supply.

Although other, more technical, requirements could be listed, these four establish what we believe are the "boundary conditions" for an oil shale retort. Two processes have been tested sufficiently at the pilot-plant level to show promise of meeting these conditions. These are what are usually termed the "Bureau of Mines retort" and the "Union Oil retort."

In the bureau's retort—also known as the "gas-combustion process"—oil shale flows continuously from top to bottom by gravity. As the shale moves down, it is heated to retorting temperature by direct contact with a stream of hot gas rising from the gas-combustion and retorting zones near the middle of the retort vessel. The oil shale leaves these zones in the form of a hot shale ash (sometimes called "spent shale"). Near the bottom of the retort the ash is cooled by a cold stream of gas (recycled from the top of the retort), which is, in turn, heated. As the hot gas moves upward from the retorting zone, it sweeps the oil vapors with it. When these vapors contact the cool, incoming shale, they condense, for the most part, into minute droplets of oil, which are recovered as a vapor-and-mist mixture from the gas stream diverted near the top of the vessel. Between 1950 and 1955 the Bureau of Mines built and operated three pilot-plant models of this retort at their experimental station, located on the U.S. Navy oil-shale reserve near Rifle, Colorado. The largest model operated successfully, though intermittently, at rates in excess of 200 tons per day. However, since Congress did not include an appropriation for this experimental station in the federal budget for 1956, the plant is now closed. The Navy has taken over the station and holds it in "stand-by" condition.

Interior of U.S. Bureau of Mines' experimental oil shale mine near Rifle, Colorado. [Courtesy U.S. Bureau of Mines]

The Union Oil retort has been under development for more than 10 years. Two small pilot-plant models have been constructed and operated, the largest at rates of from 30 to 50 tons per day. Technically, the process is known as a continuous, underfeed, countercurrent retort (Fig. 2). Its unusual feature is that relatively large pieces of crushed shale are fed from the bottom; a large ramlike piston serves as a rock pump (Fig. 3). As the shale is pumped slowly upward, it is contacted by hot gases that are pulled downward by blowers. These hot gases, which result from the burning of the residual carbon in the oil shale ash, convert

the organic matter into shale oil and combustible gas, which are withdrawn from the bottom of the unit. The shale ash continues upward, where it is broken up by rotating plows and is then removed from the top. Since the shale oil condenses on the cool, incoming shale, the process needs no cooling water.

The Union Oil Company owns, near Grand Valley, Colorado, about 40,000 acres of land underlain by mahogany ledge oil shale. Our geologists have estimated that our section of the mahogany ledge deposit contains the equivalent of 5 billion barrels of shale oil. This is roughly 10 times our present proved crude oil reserve. Thus, we have much at stake in developing a successful retort. We remain convinced, as representatives of the company have said several times before, that the Union Oil retort shows real promise of becoming a dependable, economic retort of a type that is needed for Colorado oil shale. Other retorts may, of course, be developed that could cause us to change this view. The Denver Research Institute, for example, is working, under contract from the Oil Shale Corporation of Nevada, on a 25-ton-a-day model of a retort that is based on a Swedish design known as the "Aspeco process." (This process involves passing finely ground oil shale through a ball mill, where it moves counter to a stream of heated ceramic balls. Later, by combustion of carbon remaining in the shale ash, the balls are reheated and returned to the retort.) In addition, Esso Research and the Bureau of Mines have individually done research on retorting by the "fluidized" or "entrained" solids method (in which the oil shale is crushed to very small particles and is retorted by injecting it in a stream of superheated gas, air, or steam), and the Sinclair Oil Company has carried on some very secret experiments on underground, in-place retorting. Who knows what lies ahead? We certainly do not. But until we see a better process, Union Oil's research effort will continue to be directed toward developing the Union Oil retort.

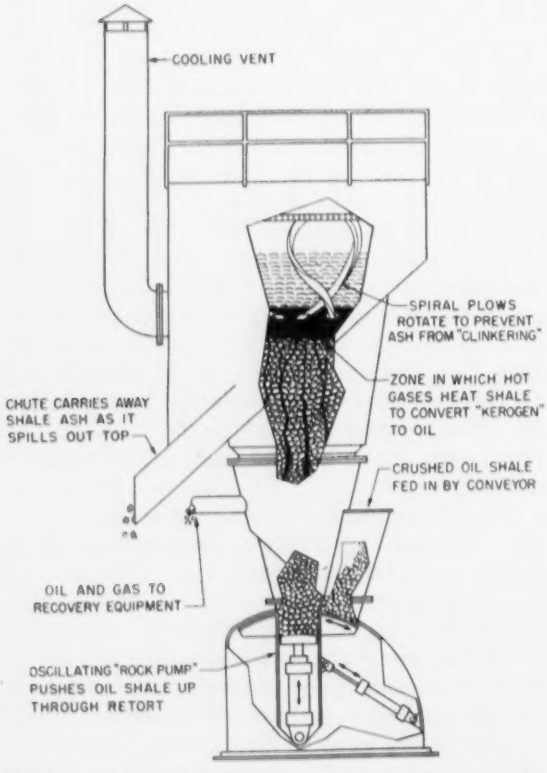
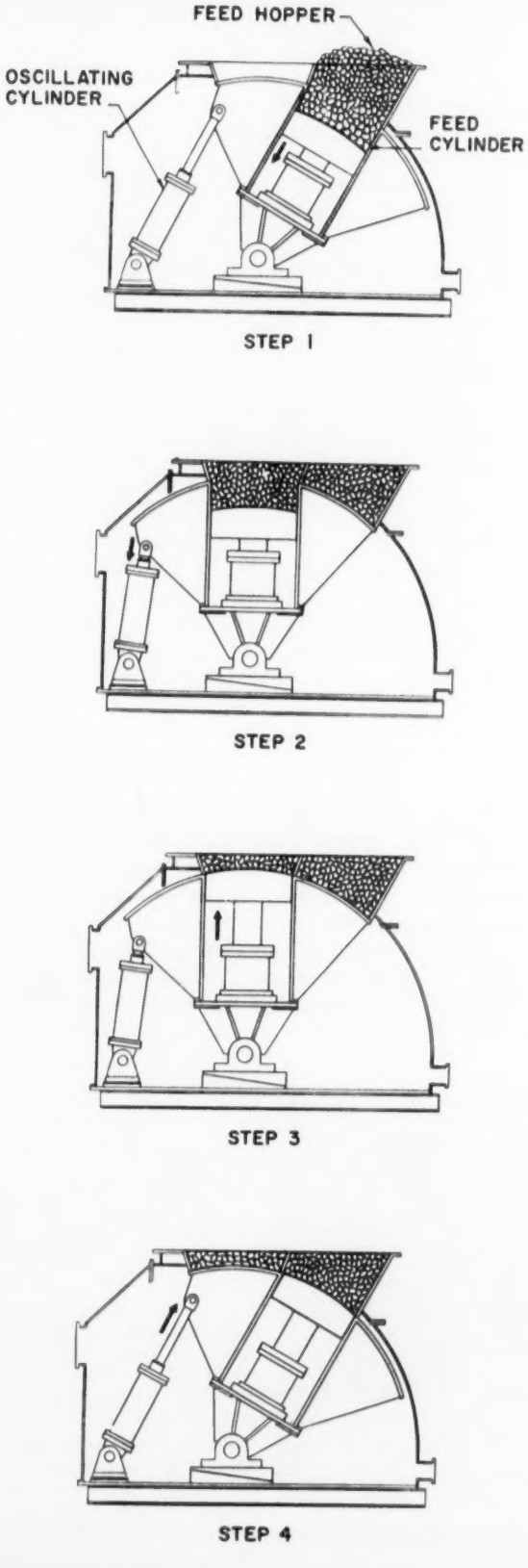

COOLING VENT
SPIRAL PLOWS ROTATE TO PREVENT ASH FROM "CLINKERING"
ZONE IN WHICH HOT GASES HEAT SHALE TO CONVERT "KEROGEN" TO OIL
CHUTE CARRIES AWAY SHALE ASH AS IT SPILLS OUT TOP
CRUSHED OIL SHALE FED IN BY CONVEYOR
OIL AND GAS TO RECOVERY EQUIPMENT
OSCILLATING "ROCK PUMP" PUSHES OIL SHALE UP THROUGH RETORT

Fig. 2. In the pilot plant model of Union Oil Company's shale retort, shale is fed in at bottom and retorted in center section, and the shale ash is removed by a chute near the top.

The shale oil that flows from the retort—usually called "raw shale oil"—bears little resemblance to the typical crude oil. It is a black, highly viscous oil that contains appreciable quantities of nitrogen and sulfur. Once it cools below 90°F, it is as difficult to pour as a barrel of frozen Jello. An additional, more complex difference between shale oil and crude oil is that shale oil contains many "unstable" molecules that have a tendency to react with one another and with other molecules to form gums and similar undesirable compounds. While these "unstable" molecules are also found in crude oil, they rarely occur in sufficient quantity to create processing problems, as they do in shale oil.

The processing route for producing marketable products from shale oil differs from that for typical crude oil principally in that preliminary steps are required to bring shale oil up to the level of a good crude oil. In practice, shale oil is processed in much the same way as are the high-sulfur, heavy crude oils found in many of California's oil fields. The essential processing steps needed to "upgrade" shale oil to the level of a good crude oil are those that (i) remove most of the nitrogen and sulfur, and (ii) eliminate or "rearrange" the molecules that are responsible for shale oil's annoying characteristic of hardening, once it cools.

The two processing steps that have proved their ability to accomplish this upgrading are (i) "coking," the use of heat to convert a small part of the oil to coke, leaving the remainder as a lighter, freer-flowing oil, and (ii) "hydrogenation," the bringing of coked shale oil and hydrogen together, at high temperatures and pressures, in the presence of a catalyst. These two steps convert the shale oil into a light, highly marketable crude oil that is essentially free of sulfur and nitrogen. This oil can then be refined, without difficulty, in the conventional re-



finery to produce 100-octane gasoline, military-specification jet fuel, diesel fuel, and other top-grade petroleum products. These products will be indistinguishable from those produced from the best crude oils.

We wish to add that Union Oil's new hydrogenation process—we call it "Unifining"—has proved to be an excellent hydrogenation method. This process, which was originally developed to upgrade high-sulfur, heavy crude oils, is winning widespread industry acceptance as a means of removing impurities and of upgrading all types of oils. Currently, more than 60 Unifining units are in operation, under construction, or planned in this country and abroad. Thus, we believe that the problem of converting raw shale oil to the equivalent of a high-gravity crude oil is solved.

Bituminous Sand

After this rather lengthy discussion of oil shale, we turn to the second part of our topic, the heavy oil deposits known variously as "asphalt rock," "oil sand," "tar sand," or "bituminous sand." At Union Oil we prefer the last-mentioned term, since it is the most accurate. Our comments on bituminous sand are, unfortunately, much less detailed than those on oil shale. This should not be interpreted to mean that the bituminous sand reserves are necessarily of any less world-wide importance. It means, instead, that there have been fewer studies, fewer reports, and fewer attempts at commercial operation. Unlike oil shale, oil from bituminous sand is not, to the best of our knowledge, produced anywhere in the world today on anything approximating a commercial scale.

It is difficult to give an all-inclusive definition of "bituminous sand" because of the differing characteristics of the many deposits that are called by that name. Generally speaking, however, by "bituminous sand" we mean a sand or sandstone impregnated with an extremely heavy oil that we generically call "bitumen." (The words *asphalt* and *tar* are also sometimes used.) When we contrast this resource with oil shale, we find these fundamental differences: Bituminous sands do contain oil as such; and unlike oil shale, which requires high-temperature retorting, the oil can be extracted by several methods; these include washing, use of solvents, and low-temperature distillation.

Fig. 3. The "rock-pump" in the Union Oil Company retort requires four operations: (i) it takes a fresh charge of shale, (ii) moves into pumping position, (iii) pumps shale into retort, and (iv) returns for the next charge of shale.

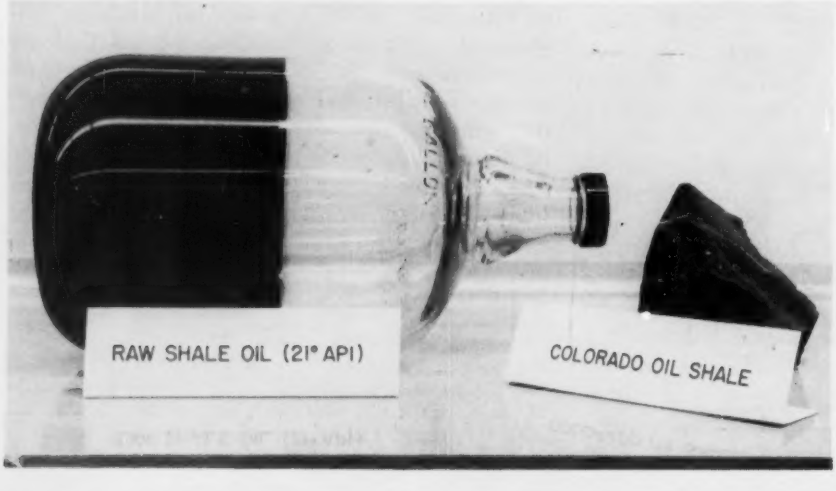
Just as the experts debate the origin of oil shale, they also disagree on the origin of bituminous sand. Many of the small deposits found in the western part of the United States seem to be, in essence, "fossil oil fields" (*10*). These deposits are apparently residues of petroleum that reached their present position by moving through porous rocks as a liquid. When the "light fractions" evaporated, the heavy residue was left impregnated in sand or sandstone. An important deposit near Vernal, Utah, apparently had a slightly different origin. Here the oil seeped into fresh-water streams that drained into a flat basin. The light oil fractions evaporated, and the bitumen settled to the stream bottom, where it mixed with sand, rocks, and other debris before eventually moving to the drainage basin (*11*). Recent press announcements report that Standard Oil Company of Ohio has made a substantial purchase of land in this deposit.

The world's largest known bituminous sand deposit, one that we discuss in more detail subsequently, is found adjacent to the Athabaska River surrounding Fort McMurray in the Canadian province of Alberta. The origin of this vast deposit seems to be the biggest mystery of the lot. At least five separate theories have been proposed, no one of which seems entirely consistent with observable facts. One astute geologist wrote recently that "[this] formation is undoubtedly one of the most fruitful fields for mental gymnastics known to geologists" (*12*). Some chemical analyses have suggested that the Athabaska bitumen represents, in the main, a product intermediate between the original organic matter and true petroleum.

When we attempt to inventory the world's bituminous sand reserves, we find that our previous oil shale inventory now seems, by contrast, as accurate as a chief auditor's balance sheet. With the exception of data from some studies of a few deposits in Utah, Texas, and California and from scattered tests in the Athabaska reserve, practically nothing is known of the richness or extent of the world's bituminous sands.

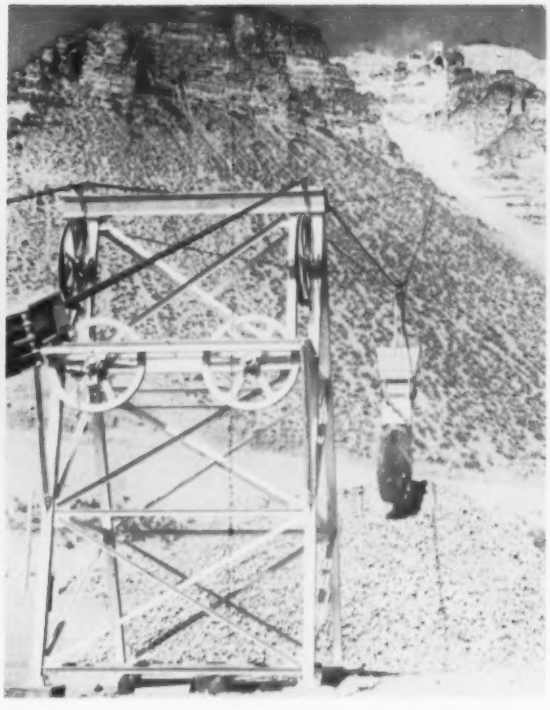
In the United States there are probably five or six deposits that are rich enough (that is, have a yield of from 20 to 40 gallons of bitumen per ton) and sufficiently adaptable to low-cost mining to have commercial significance. In the order of their apparent importance, these are the deposits near the towns of Vernal and Sunnyside, Utah; Uvalde, Texas; and Edna, California. In addition, there are a few other deposits in California of possible importance; these include one in the mountains near Santa Maria, known as the "Sisquoc" deposit. The total quantity of oil contained in all these formations has been estimated by the U.S. Geological Survey at from 2 to 3 billion barrels (*13*). Thus, the United States' bituminous sand reserve is insignificant by comparison with the vast potential of our oil shale reserve. Our knowledge of deposits other than those in the United States and Canada is almost nonexistent. Ayres and Scarlott (*4*) report that large bituminous sand formations are believed to exist in Venezuela and Mesopotamia. They mention guesses of many "billions of barrels of reserves." But until further data are gathered, we must take such information for what it is, simply guesses. Thus, we conclude that the Athabaska deposit in northern Alberta is the only one known that is large enough to be of really world-wide importance.

Estimates of this deposit's areal extent vary from a few thousand to at least 30,000 square miles. Outcrops are visible along the banks of the Atha-



Raw shale oil and oil shale rock. The bottle of oil is laid on its side to illustrate the difficulty of transporting shale oil by pipeline, once it cools to room temperature. At temperatures below 90° Fahrenheit, the heavy wax content of the oil gives it the consistency of Jello.

Union Oil Company's demonstration plant. Here a truck is getting in position to dump freshly mined oil shale into the primary crusher. The retort is in the valley below.



Union Oil Company's demonstration plant. Lower aerial tram tower with bucket dumping 2 tons of crushed oil shale.

baska River for more than 100 miles (*14*). The accepted range of total oil reserve for the deposit (based on perhaps 300 core holes) is from 100 to 300 billion barrels, although Ayres and Scarlott (*4*) mention an estimate as high as 500 billion. Whatever the number is, we can be positive that it is enormous. Almost certainly it is at least comparable in size to that for the mahogany ledge oil shale reserve.

But when we view the Athabaska deposit in terms of our threefold classification of "total reserve," "total recoverable reserve," and "total economic reserve," we obtain a different picture. Unfortunately, by far the greatest part of this formation lies tilted beneath an overburden 500 to 1800 feet deep (*10*). When we take the nature of the formation and the overburden into account, it seems unlikely that we could ever succeed in recovering this ore economically by known underground mining methods. Open-pit mining, on the other hand, seems to be applicable only to those few places that have both a thin shelf of overburden and a thick layer of bitumen. Just what share of the total this "economic reserve" amounts to is, of course, not known. Various experts have guessed that it cannot exceed 1 or 2 percent of the total (*4, 10, 15*). If we accept 2 percent as an upper limit, we must place the economic reserve at not more than 5 billion barrels. Developments of the future could—and probably will—increase this number. For example, if a low-cost underground recovery method were developed, the economic reserve could be increased, almost overnight, from 5 to more than 100 billion barrels.

Bituminous Sand Technology

From this appraisal of the quantity of bituminous sand available, we turn next to a brief account of the technology for processing it. Since most experiments have been limited to the Athabaska formation, our comments are likewise so limited.

The sand will be mined from large open-pit mines. Once the overburden has been removed, the sand can be stripped, in some cases, directly by a power shovel; in others, after a small amount of blasting (*14*). Where rocks occur, they would be removed, and the material would then be transported to the treatment plant.

At least five methods have been proposed for the extraction of the bitumen (*16, 17*). These are (i) solvent extraction, (ii) the hot-water washing

General view of Union Oil Company's demonstration plant. Aerial tram dumps crushed shale in pile at lower right. Underground tunnel feeds into secondary crusher and then to conveying and classifying system that moves shale of various sizes (depending on the nature of experimental work) to shale retort, shown (under construction) at left of towerlike structure at end of long conveyor, above large oil storage tank.

method, (iii) the cold-water washing method, (iv) some form of low-temperature retorting, and (v) the most recent method, called the Coulson process, which involves separation of the oil from the sand by centrifugal force. The solvent-extraction method is based on the fact that certain solvents are capable of dissolving the bitumen from the sand. The hot- and cold-water methods involve the use of large quantities of water to separate the bitumen in the form of a floating "froth," which can be skimmed off. By low-temperature retorting, it is possible (though apparently quite costly) to heat the sand until the bitumen can be separated as a flowing oil. The Coulson "centrifuge method" involves the addition of a diluent, such as kerosene, to the sand and then separation of both the bitumen and diluent by spinning them in a large centrifugal machine.

Since none of the methods have been tried on a sufficiently large scale to determine their comparative characteristics, it is difficult to determine which is the most promising. From reports in the technical journals, it appears that the hot-water washing method has received the most research effort, much of it sponsored by the Alberta Government. But, for the past year, two private Canadian companies (Can-Amera and Royalite) have been experimenting on a fairly large scale with the "centrifuge" method (*17*).

Once the bitumen has been extracted from the sand—and, we should add, the sand extracted from the bitumen—the processing steps required to convert the oil to commercial products are straightforward. The oil is nothing more nor less than a very heavy crude oil that contains an unusually large amount of sulfur, possibly 5 percent by weight

(*16*). Although it is not an especially desirable oil from the standpoint of the refiner, thousands of barrels of just such a crude oil are being produced and refined every day in California.

The first two processing steps are the same as for shale oil: "coking" followed by "hydrogenation." Since the bitumen contains less nitrogen than shale oil does, the hydrogenation can be less severe and, consequently, less costly. Just as in the case of shale oil, we have found Union Oil's Unifining process capable of being adapted to the hydrogenation step. After hydrogenation, the bitumen is a high-gravity crude oil that is capable of being further refined to conventional products by conventional methods.

What Lies Ahead?

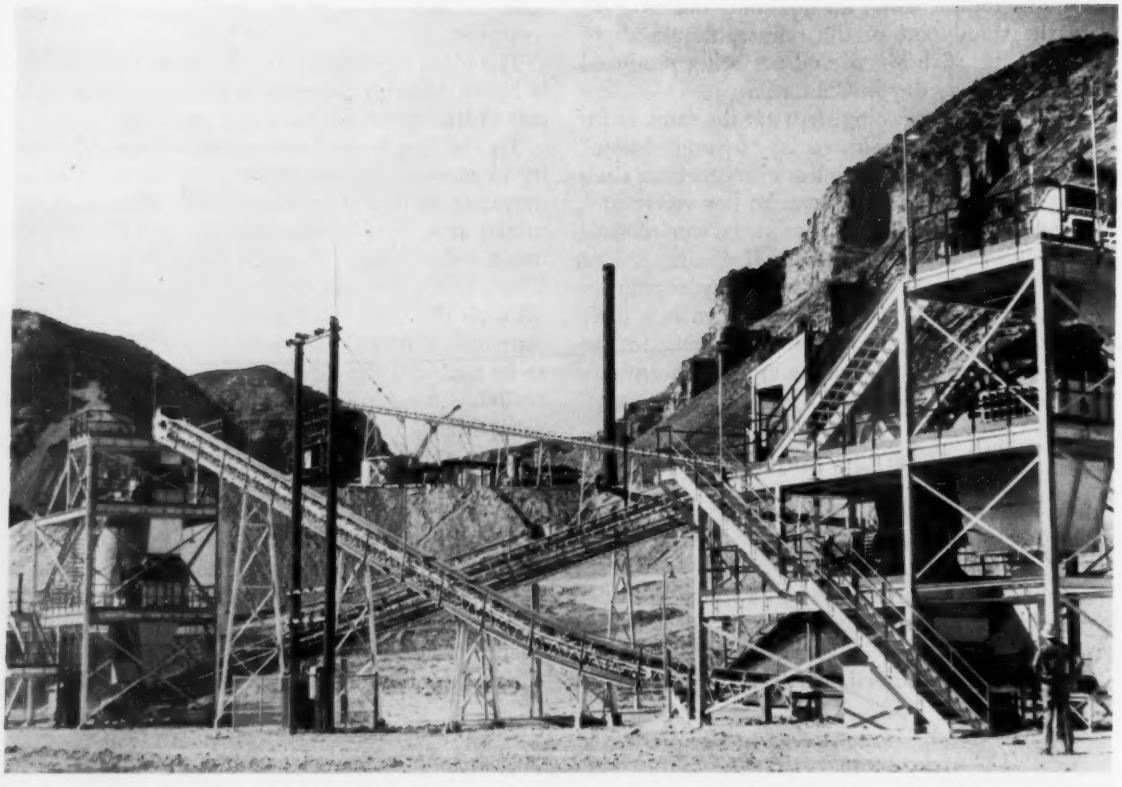
We now reach the final, perplexing, but inevitable part of our survey: What lies ahead for oil shale and bituminous sand? We need hardly say that our views represent no more than "educated guesses"; our view of the future is as cloudy as anyone else's. We do, however, see one significant trend that, if continued, will certainly affect the future of these two, as yet, practically undisturbed resources.

The trend we refer to is well known to all oil men in North America; we refer to the continually rising cost of finding new supplies of crude oil.

The United States has shown a remarkable ability to increase its consumption of crude oil at an average rate of 4 to 6 percent each year. At a sustained rate, such "compound interest" growth will mean a doubling of demand every 15 years or so. Thus, 1956's demand of 9.3 million barrels of crude oil each day could well become 18 million barrels sometime between 1970 and 1975. It hardly needs to be said that the United States petroleum industry has a monumental task ahead in finding oil to satisfy this growing thirst.

How much oil will be found in the United States? We are certainly ill-equipped to say. However, many eminently qualified people have discussed this subject in recent months and have generally reached about the same conclusion. A partial list of the forecasters includes Eugene Ayres (*18, 19*), consultant for Gulf Research and Development; Joseph Pogue and Kenneth Hill (*20*) of the Chase Manhattan Bank; M. King Hubbert (*21*),

Union Oil Company's demonstration plant. The top of retort, as it nears completion, is shown at left center.



Union Oil Company's demonstration plant. View of the secondary crusher and the conveying and classifying system for transporting oil shale to the retort, which is seen, under construction, in the background.

consultant for Shell Development; Albert Nickerson (*22*), president of Socony-Mobil Oil Company; and David Staples (*23*), president of Tide Water Oil Company. In broad terms, their common conclusion is this: crude oil production in the United States will reach its peak in the next 10 to 20 years and then decline slowly thereafter.

If we accept this conclusion, it seems almost inevitable that energy costs must increase also, at least to the point where the most favorably situated bituminous sands and the richest oil shales can compete with crude oil in the market place.

When will this occur? Plant-construction time alone prevents production of either shale oil or bituminous sand oil before 1960. If current research efforts are successful, then, from 1960 on, the volume could expand rapidly, as accumulating "know-how" pushes production costs down, while competing energy costs continue to rise. Ayres (*19*) has forecast shale oil production of more than 1 million barrels a day by 1975. Certainly there will be a ready market for this oil without disturbance of the pattern of domestic production.

The Union Oil Company is currently involved in the most ambitious oil shale research and demonstration program ever undertaken by a private company. Our research work is aimed at (i) designing, constructing, and operating a commercial prototype of the Union Oil retort, (ii) establishing experimentally optimum shale oil refining conditions, and (iii) planning and integrating the processing steps that lead to the most profitable output of what we call "commercial shale oil." When our program is completed (toward the end of 1957), we expect to have learned enough of technology and costs to answer the critical question: Is shale oil competitive with crude oil? This is an expensive question, since we now believe it will cost about $7 million to answer it.

The large-scale retort has been designed, and construction is approaching completion at our research plant site about 12 miles from Grand Valley, Colorado. We started shakedown tests in December and should soon be producing some shale oil. The capacity of this retort will be in excess of 300 tons per day. In commercial practice, nests of such retorts would operate as a unit, with each nest having common oil and gas collection equipment. Each nest probably would have capacity in excess of 1000 tons per day.

Finally, we wish to emphasize the fact that, while we foresee oil shale development not many years away, we also see some stubborn roadblocks ahead. The four most important are the following.

Retorting technology. While Union Oil has made real strides with its retorting research, we know that our present design will evolve many times before research on oil shale retorts will no longer be profitable. When we look at our modern automobiles and airplanes, we sometimes forget that they evolved ever so slowly from the "model-T" and the "biplane" of 40 years ago.

Adequate water supplies. This is a difficult and, to the people of Colorado, a controversial subject. We wish only to emphasize one point: a large oil shale industry will need large quantities of water. We hasten to add that water is needed not for retorting, for, as we emphasized earlier, we are convinced that self-cooling retorts are possible. Rather, water is needed for the essential refining steps that must be carried on near the retorts. The raw shale oil cannot be transported until it has been at least partially refined. In addition, water is needed for the plant workers, their families, and the local industries. If Colorado fails to reserve water for a future oil shale industry, the entire pattern of development can be distorted or even destroyed.

Equitable federal tax treatment. This, like all tax problems, gets more involved the more you think about it, and we will attempt no discussion here. Federal tax laws now make inadequate provisions for oil produced from oil shale. This is something that only Congress can correct.

Large initial capital investment. Our studies indicate that a large, complete oil shale plant, including the necessary partial refining steps, will cost initially from $3000 to $5000 for each barrel of daily capacity. Thus, a 20,000-barrel-a-day plant will cost between $60 and $100 million; a 100,000-barrel-a-day plant will cost in excess of $300 million. Clearly, an oil shale industry will be a big venture, requiring many companies and many thousands of investors.

In conclusion we wish to add that, despite the difficulties, we have confidence in oil shale's future. Other new industries have faced and surmounted more difficult problems. But those who are enthusiastic about oil shale must not underestimate the difficulties that lie ahead. Converting Colorado's "mountains of oil" into usable energy is a challenge of the first magnitude. Nature has presented man with a mighty tough task.

References

1. K. E. Stanfield *et al., Bur. Mines Rept. of Investigations* 4825 (Nov. 1951).
2. W. H. Cadman, *J. Inst. Petroleum* **34**, 109 (1948).
3. R. D. George, *Bull. Colo. Geol. Survey* 25 (1921), p. 21.
4. E. Ayres and C. A. Scarlott, *Energy Sources—the Wealth of the World* (McGraw-Hill, New York, ed. 1, 1952).
5. A. C. Rubel, "Shale oil as a future energy resource." Paper presented before the Interstate Oil Compact Commission (Denver, Colo., 17 June 1955).
6. C. Belser, *Petroleum Technol.* **11**, No. 3, 1 (1948).
7. R. J. Cameron, "The processing of Colorado oil shale." Paper presented before the 59th annual convention of the Colorado Mining Assoc. (2 Feb. 1956).
8. S. Klosky, *Bur. Mines Bull.* 468 (1949).
9. ———, *ibid.*, 556 (1956).
10. L. M. Fanning, *Our Oil Resources* (McGraw-Hill, New York, ed. 1, 1945).
11. G. D. Shea, *Bur. Mines Rept. of Investigations* 4871 (May 1952).
12. J. C. Sproule, *Proc. Athabaska Oil Sands Conf.* (Sept. 1951), pp. 6–25.
13. U.S. Senate Committee on Interior and Insular Affairs, *Stockpile and Accessibility of Strategic and Critical Materials to the U.S. in Time of War.* Hearings before the Special Subcommittee on Minerals and Materials and Fuels Economics, 83rd Congress, pursuant to S.R. 143 (1953–54), p. 118.
14. S. M. Blair, *Report on the Alberta Bituminous Sands* (Govt. of the Province of Alberta, Edmonton, Dec. 1950).
15. P. C. Putnam, *Energy in the Future* (Van Nostrand, Princeton, N.J., 1953).
16. D. S. Pasternack, *Petroleum Engr.* **25**, No. 2, A58, 60, 65, 66, 68 (Feb. 1953).
17. Anon., *Oil Gas J.* **54**, No. 14, 72 (1955).
18. E. Ayres, "Energy resources for the future." Paper presented before the Interstate Oil Compact Commission (Denver, Colo., 17 June 1955).
19. ———, *Sci. American* **195**, No. 4, 43 (Oct. 1956).
20. J. E. Pogue and K. E. Hill, "Future growth and financial requirements of the world petroleum industry." Paper presented before Am. Inst. Mining Met. Engrs., Petroleum Br. (21 Feb. 1956).
21. Anon., *Petroleum Week* **2**, No. 11, 9 (1956).
22. A. L. Nickerson, "Future world demand for oil." Paper presented before the Texas Mid-Continent Oil and Gas Assoc. (Dallas, Tex., 4 Oct. 1955).
23. D. T. Staples, "Our future petroleum supply—let's face the facts." Paper presented before the California Natural Gasoline Assoc. (Pasadena, 12 Oct. 1956).

Nautical Charting (1807-1957)

AARON L. SHALOWITZ

The author has been associated with the Coast and Geodetic Survey since 1916 in capacities that range from field surveyor and cartographic engineer to his present position of special assistant to the director of the survey and chief of the technical research and information staff. He collaborated in the preparation of the Hydrographic Manual *of the Coast Survey and is the author of numerous reports and published papers on hydrographic surveying and related subjects. From 1943 to 1952 he was editor-in-chief of* Surveying and Mapping, *and he is at present editor of the* Journal of the Coast and Geodetic Survey.

TO a maritime nation, such as the United States, the safety of its waterborne commerce is dependent on a full and complete knowledge of the coast—its nature and form; the depths of the water and the character of the sea bottom near it; the locations of reefs, shoals, and other dangers to navigation; the rise and fall of the tides; the direction and strength of currents; and the behavior of the earth's magnetism in areas that must be navigated. Such information is furnished by the nautical chart. Without the chart, our great ports and harbors would be as effectively closed to maritime commerce as they would be if they were blockaded by an enemy fleet.

The need for charting the coast was recognized almost from the beginning of our national independence. The young nation was concentrated along the Atlantic coastal plain, fisheries and shipbuilding were important industries, and waterborne commerce between the harbor cities was the medium for the movement and exchange of fish, shipbuilding materials, and other products. To promote that commerce and to develop trade with foreign nations, President Jefferson, on 10 February 1807, signed into law the act that set in motion the machinery for surveying and charting the coast and harbors of the United States, together with the outlying islands and fishing banks. This was the inception of the Coast Survey, and it is this historic event that we are observing this year—150 years later.

Early Pioneers

In commemorating this century and a half of charting progress, we cannot fail to take note, at the outset, of the many men of science and engineering who were associated with the Coast Survey and who, in their respective fields, broadened its horizons—men such as George Davidson, author of the *Pacific Coast Pilot* of 1889, the most complete record of the coast ever to be published for the use of the mariner; Rollin Harris, who pioneered in the field of tidal research and published a voluminous *Manual of Tides,* in which a new and comprehensive theory of tides was formulated; Charles Schott, who for 50 years directed all the intricate computations and adjustments of field observations required in the geodetic, magnetic, cartographic, and tidal operations; and John Hayford, whose investigations of the size and shape of the earth resulted in the derivation of a new figure, the International Ellipsoid of Reference. These are only a few in a long roll—a roll of honor in the annals of the Coast Survey. But tribute, in particular, should be paid to two early leaders—Ferdinand Hassler and Alexander Bache—under whose direction the Survey evolved from a mere concept into an organizational entity with a fully developed plan of execution that became easily adaptable to a developing and expanding America. Both bequeathed to the Coast Survey a heritage of zeal and singleness of purpose that has been an inspiration to those who have followed them.

Ferdinand R. Hassler

Ferdinand Hassler (Fig. 1) may rightly be called the "father of the Coast Survey." It was his plan that President Jefferson accepted for the survey of the coast, and it was he who was later entrusted with its direction. It was fortunate for the country in general, and for the Survey in particular, that so far-seeing a person as Hassler, with the indomitable will and courage of the pioneer, was chosen to organize and direct operations. Hassler immigrated to the United States in 1805, at the age of 35, after filling a number of the most important official positions in his own land, Switzerland, among them those of head of the Geodetic Survey of Switzerland, attorney general, and member of the Supreme Court.

Hassler's fundamental plan provided for a division of operations into three great branches—the geodetic, the topographic, and the hydrographic. Of these, he considered the geodetic operation to be the most important, for it affected the accuracy

and final value of the other two. Hassler's plan had the approval of the most eminent scientists of Europe and of this country. It is a tribute to his farsightedness and his genius that his original plan of organization, broadened and thoroughly worked out in succeeding years, is still the fundamental directing plan of the Survey a century and a half after its adoption.

The difficulties that Hassler faced would have completely discouraged one of less strength and fortitude. Instruments such as those necessary for a geodetic survey were not available in this country at the beginning of the 19th century. Hassler had to prepare his own drawings and designs, and some of the more important ones, such as theodolites and chronometers, that were eventually constructed for him bear the impress of his inventive genius in the shape of modifications and improvements that he devised. It is an interesting fact that not a single working observatory for the training of astronomers existed in this country at that time, and there was not a single college that included a course in geodetic surveying in its curriculum.

Although the need for results was urgent, the level-headed Hassler fortunately did not allow himself to be stampeded into haphazard decisions. Instead, he approached the great task scientifically and never deviated from the high standards he set for the work. He knew that the survey of the coast, if it were to have a lasting value, could not be attacked as a problem of ordinary surveying. The operations were to be bound together by a trigonometric survey, with long lines, and executed by the most accurate instruments and the most refined methods. The best of foundations was thus laid for the geodetic operations of the Coast Survey. This was Hassler's great contribution. Had he planned to meet only the needs of his time, he would have effected a negligible saving, and his work would have had to be done over at greater expense in later years. Instead, the first Hassler surveys meet modern requirements and, today, form part of the permanent primary network of the country.

Alexander Dallas Bache

When Hassler died in 1843, the foundation for the survey of the coast had been laid, and the detailed surveys of the ports and harbors were begun with a survey of the approaches to New York Harbor. The building of the superstructure fell to his successor in office, Alexander Dallas Bache (Fig. 2). Bache was the great-grandson of Benjamin Franklin and a grandson of Alexander Dallas, Secretary of the Treasury under President Madison.

Fig. 1. Ferdinand R. Hassler, first superintendent of the Coast Survey.

During his lifetime, Bache held many responsible posts, any one of which might have been considered the successful culmination of a life's work and ambition. His rise to positions of prominence in the fields of education and science was meteoric. As a West Point cadet he distinguished himself by his scholastic excellence, graduating at the head of his class at the age of 19. At 22 he was named to the faculty of the University of Pennsylvania as professor of natural philosophy and chemistry. In addition to his 8 years at the university, his service to American education included the presidency of two of our foremost schools, Girard College and the Central High School of Philadelphia; the general superintendency of a city school system; and the publication of a monumental work on European education, the result of 2 years of intensive study abroad.

Bache attained preeminence while serving as head of the Coast Survey. His selection to this important scientific and technical post had the concurrence of all the principal scientific and literary institutions of the country. It was said that no such weight of recommendation was ever brought, at any time, in support of any other candidate for office on purely intellectual grounds.

In original concept, the plan for the survey of

the coast was Hassler's, but Bache gave it form and direction. Hassler built on a rigid scientific foundation; Bache adapted that plan to an expanding America. (Texas, California, Oregon, and Washington were added to the Union during his tenure.) His determination that the maps and charts of the Coast Survey should be carried to the door of every man who had an interest in commerce, navigation, geography, or science was an indication of his broad vision of the scope and purpose of the Survey. Under Bache's careful guidance and with his sympathetic understanding, not only did the Coast Survey keep pace with the progress in art and science but many notable and original contributions were made in the fields of practical astronomy, physical hydrography, and cartography.

Modern Charts—the End-Product of Systematic Surveys

In assessing the contributions of the Coast Survey to the development of nautical charting, cognizance must be taken of the fact that what had previously been called a chart was largely the result of exploration or of limited surveys and was generally the work of individual effort and private undertaking. The Portolanos of the 14th century, the Cosa chart of 1500, and the Atlantic Neptune charts of the late 18th century are all examples of the work of this exploratory period. These, like all the early charts, suffered from two great defects —the want of detailed surveys and the lack of a rigid system of connection between the various ports.

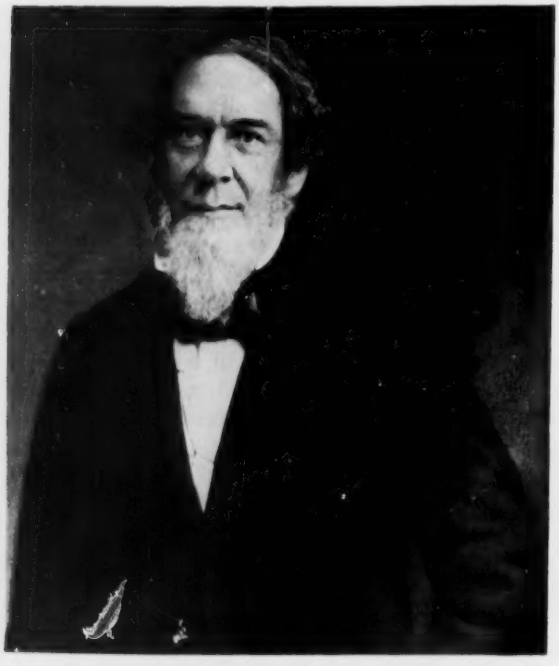


Fig. 2. Alexander Dallas Bache, who became superintendent of the Survey in 1843.

Not until the early part of the 19th century did governments begin to recognize the wisdom of systematically charting their coastal waters as a necessary prelude to their commercial intercourse with other nations. This marked a new era in chart making and was the beginning of the accurate charting of today.

The modern nautical chart is the end product of all the field operations. Into its construction enter the results of the geodetic, topographic, hydrographic, tidal, and magnetic work of the Survey (Fig. 3). Progressive improvement in the nautical chart is, in the main, coextensive with the development of systematic surveying and of surveying techniques, including instrumentation and equipment. A consideration of these components is therefore essential to any evaluation of the nautical chart proper.

Geodetic Base for Charting

That good and reliable charts can be made only from correct surveys is a truism that need not be belabored to the engineer and the scientist. No one appreciated this fact more than Hassler. From the very beginning he insisted on a strong triangulation as the backbone for all the harbor and coastal surveys, but the need for this was not so obvious to others, and, as a result, Hassler was subjected to much humiliating criticism. His scientific approach, nevertheless, prevailed, and the tradition of accuracy which he inaugurated has been steadfastly maintained through a century and a half of progressively increasing activity.

Triangulation is to the nautical chart what the steel framework is to a building—it gives it rigidity and knits together all portions into a harmonious whole. Without this framework of control, our charts would be subject to the same deficiency that characterized the charts of the Colonial period, exemplified by the Atlantic Neptune charts of Des Barres.

If a survey, or group of surveys, on which a chart is based were to be positioned with respect to the astronomical latitude and longitude of an initial point, it would soon be found that discrepancies exist in the overlapping portions of adjacent charts, and scaled distances between points that span two charts would not be true, nor would the geographic relationships be correct. Because of the varying density of the earth's crust and its effect on the plumb line, such results are inevitable if

surveys are based solely on astronomical determinations.

In any engineering or scientific undertaking that involves a large area, it is important that full coordination and correlation exist in the surveys, maps, and charts of the country. A hydrographic or topographic feature on the earth can have but one latitude and longitude, and it must be the same on every map or chart on which this feature appears. This can be accomplished only through the adoption of a single geodetic datum for the entire area—that is, by taking the position of a single point in the country as the initial or datum to which all other stations are referred. In the United States, this initial is station Meades Ranch, in central Kansas. Its latitude and longitude on the spheroid of reference were fixed by mathematical adjustment based on a study of numerous astronomical stations throughout the country that had been connected by a continuous system of triangulation. Today, the whole of the United States, through Canada and Alaska to the Bering Strait, is coordinated on this single geodetic datum—the North American datum of 1927. The establishment of this datum has resulted in complete coordination among nautical charts of the Atlantic and Gulf coasts and those of the Pacific coast and Alaska—an enviable position for any country to be in.

Recently, the distant, offshore islands in the Bering Sea were connected for the first time with the triangulation network on the mainland of Alaska by a system of trilateration, in which the sides of the triangles were measured by electronic methods, the longest line being 501 statute miles (Fig. 4). The successful completion of this project furnishes a control net for hydrographic surveys from which accurate charting of this vast, strategic area can proceed with minimum danger to men and ships.

From its modest beginnings along the eastern seaboard, the geodetic-control network of the United States has now reached continental proportions and is the foundation for all mapping and charting in the United States.

Fig. 3. The 469 field-survey sheets, sounding and tidal records, volumes of triangulation and magnetic data, and miscellaneous reports used in the making of a single nautical chart of the Coast Survey.

Advent of Photogrammetry

An important feature of the nautical chart is the land area, with its characteristic shore forms, landmarks, elevations, and depressions. In close, inshore navigation, a mariner relies a great deal on prominent shore objects to fix his position and sometimes even uses the configuration of the shore line for identification.

From the beginning, the principal instrument used in the Coast Survey for topographic surveying was the plane table. The introduction of the telemeter rod, about 1865, for measuring distances with the alidade, greatly facilitated the surveying of complex shore lines and gave the chart increased fidelity. When proper precautions are taken, a remarkable degree of accuracy is obtainable by this method of surveying.

The years preceding and following World War II saw the emergence and flowering of the new science of aerial photogrammetry—the greatest advance in topographic mapping since the prototype of the modern plane table was developed, by Johann Praetorius, in 1590. Ground topographic methods are rapidly giving way to this more economical and more expeditious method of mapping from the air. The wealth of information and fullness of detail provided by an aerial photographic survey cannot be matched by any other practicable method of surveying.

The design of a nine-lens camera (Fig. 5) by the Coast Survey, together with transforming, rectifying, and stereoplotting equipment, gave considerable impetus to our topographic survey work in Alaska, where difficult and inaccessible terrain could be bridged by this camera with a minimum of ground control.

Recently, a low-distortion, wide-angle, single-lens precision aerial mapping camera, which uses

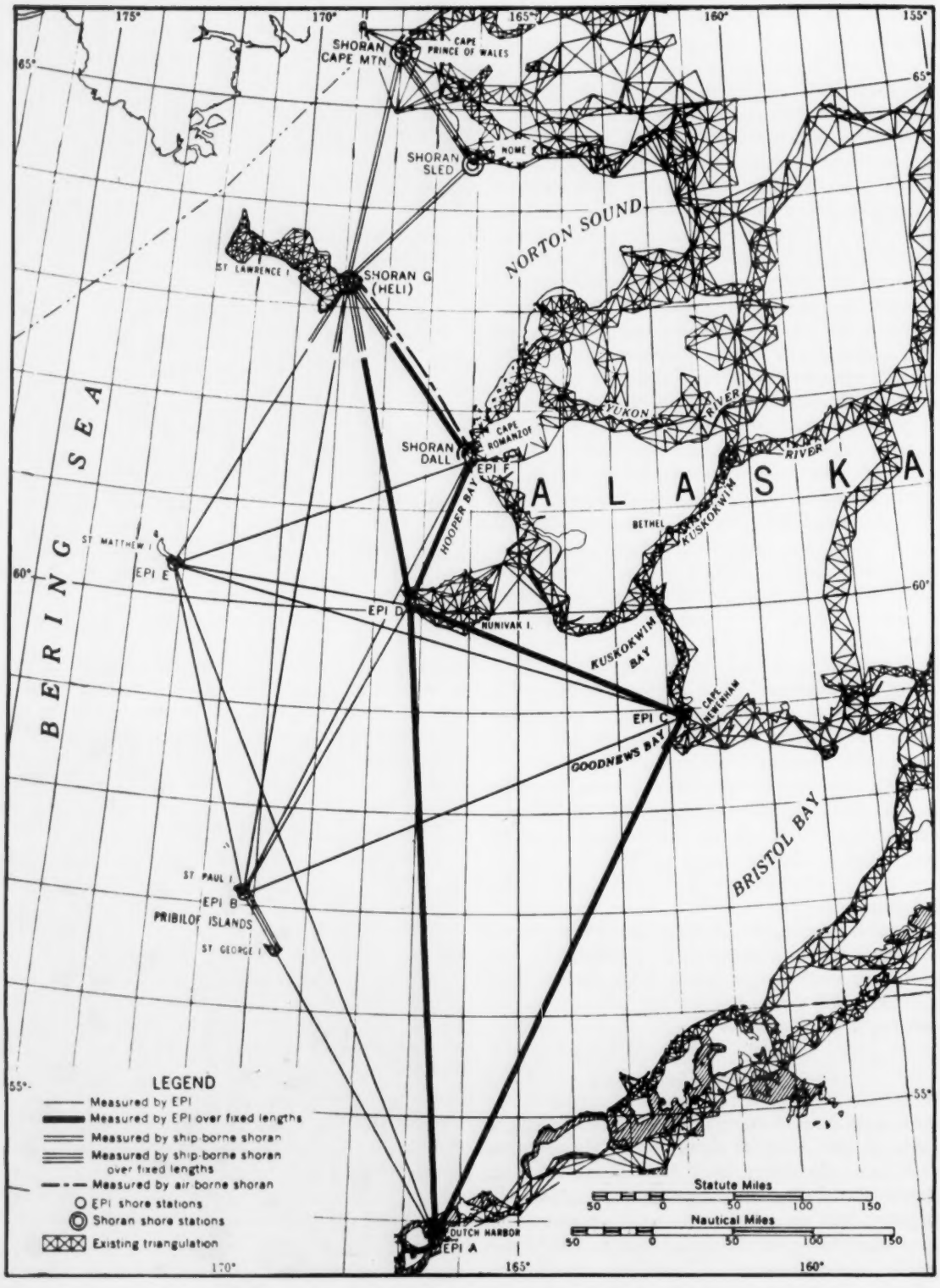


Fig. 4. Datum connection in the Bering Sea. In 1951, the distant offshore islands in the Bering Sea were connected for the first time to the mainland triangulation. This put them on the same geodetic datum as the United States.

an infrared lens cone, was acquired. The use of infrared photography for mapping the high- and low-water lines will result in greater charting accuracy of these tide lines, particularly in areas that are difficult of access for identification of shore line. Techniques are being studied for using this type of photography, in conjunction with tide observations, for charting riparian boundary lines based on tidal definition. (Figure 6 shows stereoplotting equipment used with single-lens photographs.)

The advent of photogrammetry in the Coast Survey has had two salutary effects on the nautical chart: (i) it has further increased the accuracy of the chart, particularly for inaccessible areas; and (ii) it has brought within practicable scope the immediate revision of areas where natural or man-made changes have occurred—an important factor in safeguarding our sea lanes.

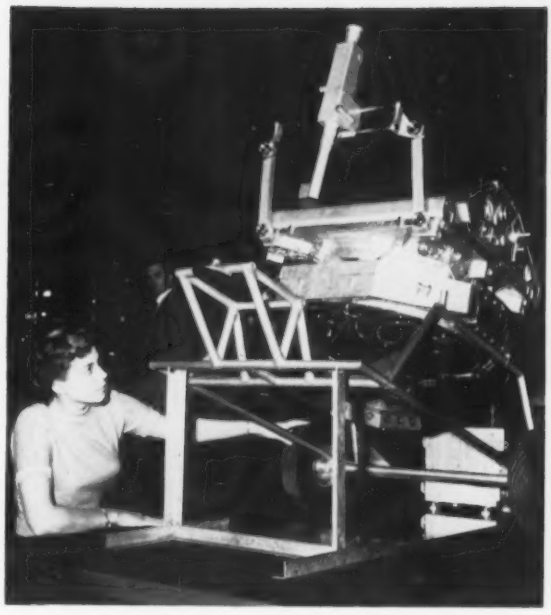


Fig. 5. A nine-lens aerial camera that was designed in the Coast Survey for mapping in areas where difficult terrain necessitates the establishment of a minimum of ground control.

Hydrographic Advances

From the standpoint of the nautical chart, the greatest advances made since the early days of charting have been in the field of hydrographic surveying. The chart can be likened to a map of the water area on which elevations above the bottom (depth soundings) are shown. Hydrography is thus the principal visible characteristic of the chart. By it the navigator is guided into the safe lanes and can avoid the known dangers.

Hydrographic surveying for charting purposes consists essentially of two simultaneous but independent operations: the measurement of depth and the determination of the survey vessel's position at the time the depth is obtained. The revolutionary advances made in this field during the past three decades have had a profound effect on the accuracy and usefulness of the nautical chart. Depth measurement by sound—better known as echo sounding—has superseded the hand lead and the wire machine, and electronics has replaced all previous, less accurate methods for determining positions.

Echo sounding is based on the principle that a sound impulse sent out by the survey vessel will be reflected from the ocean bottom and will return to the vessel as an echo, just as echoes are received in air from distant objects. From the elapsed time interval and a knowledge of the velocity of sound in sea water, the depth can be determined. Echo-sounding equipment is designed to produce the sound, receive the echoes, measure the elapsed time intervals and convert them into depths, and register the depths on a dial or in the form of a graphic profile (Fig. 7). The Coast Survey developed a precision, dial-type echo instrument (the Dorsey No. 3), which has a probable reading accuracy of $\pm 1/10$ foot for soundings up to 100 fathoms.

Methods of positioning the sounding vessel and, in turn, the soundings in latitude and longitude have undergone more radical changes during the life span of the Coast Survey than perhaps any other activity. The early hydrographers, who operated close inshore, located their positions by sextant angles on shore objects. When they were out

Fig. 6. The Kelsh plotter, one of several stereoplotting instruments used in the Coast Survey for making topographic maps from single-lens aerial photographs.

of sight of land, they made observations on the heavenly bodies or used dead reckoning. Although refinements were made in the latter methods, their application to hydrographic surveying still left much to be desired, and an accurately coordinated offshore survey was the exception rather than the rule. The first major change occurred in the late 1920's with the development, in the Coast Survey, of "radio acoustic ranging" (RAR) for measuring horizontal distances over the water by means of underwater sound transmission. This was, in reality, an adaptation of echo sounding in which the horizontal path of the sound wave was used to measure the distances from the survey vessel to two or more known stations on shore or in the water.

While radio acoustic ranging is no longer in use, having been superseded by later developments in position determination, it is noted here because of its influence on the nautical chart. Together with echo sounding, it gave us a new conception of accuracy, as applied to offshore hydrographic surveys, and laid the foundation for the development of a new type of nautical chart, which is discussed in a subsequent section of this article.

World War II ushered in the electronic era. It is well known that electronics played an important role in the prosecution of the war. "Shoran," a form of radar, was developed for strategic aerial bombing. The Coast Survey was first to adapt this technique to the problem of accurately locating a survey ship's position.

Shoran is based on the principle that electromagnetic waves travel through the atmosphere at an almost constant rate of speed—186,000 miles per second. In the familiar radar, dependence is placed on the reflection of such waves from natural objects. In shoran, this reflection is strengthened and specialized by use of responding stations set up at known points, which return intensified signals.

Shoran constitutes no new principle in hydrographic surveying, but it does apply a new and more effective technique for determining distances from control points. Shoran does the job quickly, accurately, and independent of adverse weather conditions. Being a line-of-sight system, it is limited, under practical operating conditions, to distances of 50 to 75 miles, with a probable error of 8 meters in a single measurement (Fig. 8).

To extend the operating limits of shoran, a new electronic device, called the "electronic position indicator" (EPI), was developed by the Coast and Geodetic Survey. This system combines the long-range characteristics of "loran" with the distance-measuring features of shoran and thus makes possible the measurement of distances in excess of 300 miles. EPI operates in the low-frequency range of about 2 megacycles per second and utilizes the ground wave, so that its distance range does not depend on the elevation of the control stations. The principles of position fixing with EPI are essentially the same as with shoran; both involve the measurement of small time intervals of the order of 10^{-7} second. The over-all accuracy of the system is about 75 meters and is independent of distance from the control stations. The maximum distance offshore to which EPI has thus far been carried is 550 statute miles.

The acoustic and electronic methods have steadily pushed seaward the frontiers of accurate hydrographic surveys (Fig. 9). They have made feasible the exploration of the intricate patterns of our continental shelves and slopes with an accuracy and completeness undreamed of by the surveyors who were dependent on the early methods and

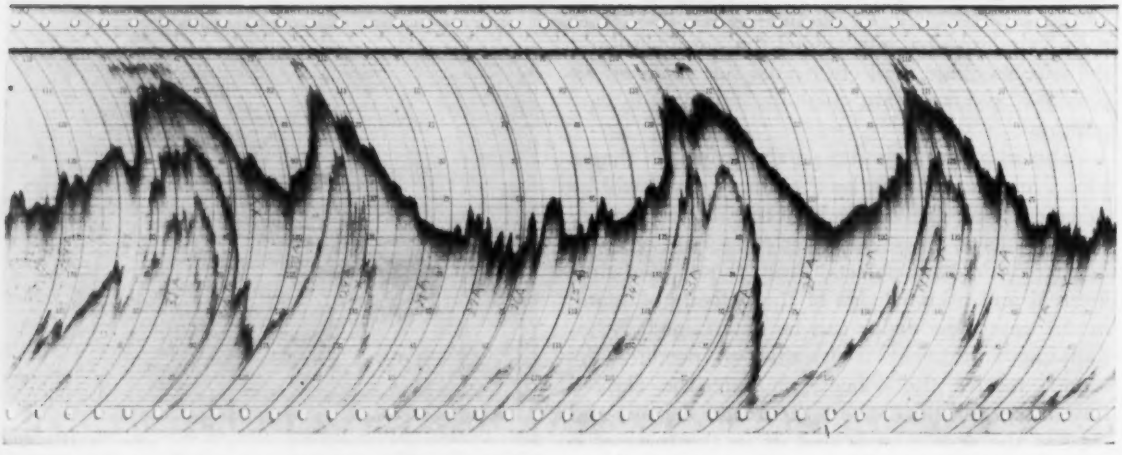


Fig. 7. A graphic recorder profile. The graphic recording type of echo sounder gives a continuous profile of the ocean bottom.

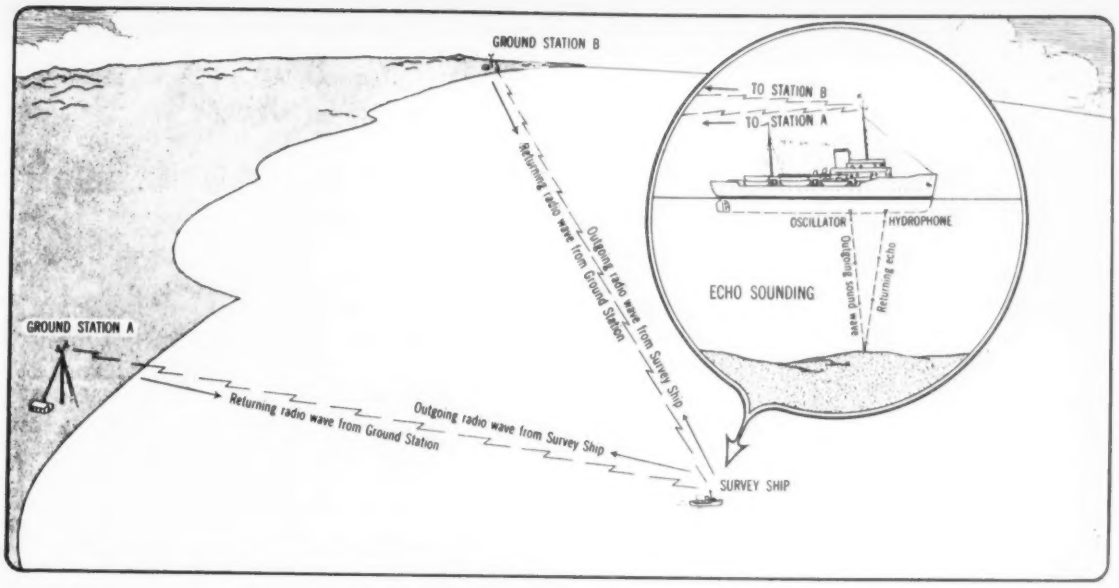


Fig. 8. Echo sounding and electronic position determination. While the ship's echo sounder measures the depths by sound, the position of the vessel is determined by electronics.

thus have added to the safety of life and property at sea. The rapidity with which great depths can be measured by echo sounding (a matter of seconds, compared with the hour or more required for each measurement by the older method) has made it possible to take thousands of soundings in areas where formerly only a few scattered ones were economically feasible. This has increased immensely our sum total of geographic knowledge. And it is a gratifying circumstance that nearly all the Coast Survey personnel who have had a part in this revolutionary change-over are still alive today.

Scientific Chart Making

What has been the impact of these developments in surveying techniques on the navigational chart? Mention has already been made of the lack of coordination that characterized the charts of the Colonial period. The first chart published under the auspices of the Coast Survey was in striking contrast to anything that had previously been called a chart of our coast. The outstanding improvements were high accuracy of geographic position, more thorough hydrography, and complete topography.

With each accession of new data, resulting from surveying developments, the nautical chart improved in accuracy standards and in coverage. But the chart also developed in its own right, cartographically. Since publication of the early charts, there has been a progression of improvements both in the character of the chart and in the methods of reproduction—all designed to enhance its value to the navigator.

Chart Compilation

Chart making is a combination of the work of the cartographer, who prepares the engineering drawing, and of the engraver or lithographic artist, who translates the drawing into a finished product for reproduction. The nautical chart, unlike many other cartographic efforts, is intended for serious use in the solution of navigational problems; hence, all the rules of engineering must be meticulously observed in its preparation.

Chart compilation is a process of selection. The usefulness and accuracy of the chart depend not only on the material that enters into its construction but also on the critical appraisal of such material and on the intelligence with which the essentials are portrayed. "Easy reading is hard writing" may well apply to nautical charts. The skilled cartographer must sift, from the mass of data before him, the important from the unimportant, the strong from the weak, the stable from the changeable. Some data he rejects entirely, some in part, and he coordinates and selects from the rest the information that is to appear on the finished chart.

In addition to these engineering elements, the chart compiler must be ever conscious of the importance of artistry in the chart. There must be no crowding of matter to confuse the navigator, and there must be no haphazard arrangement to

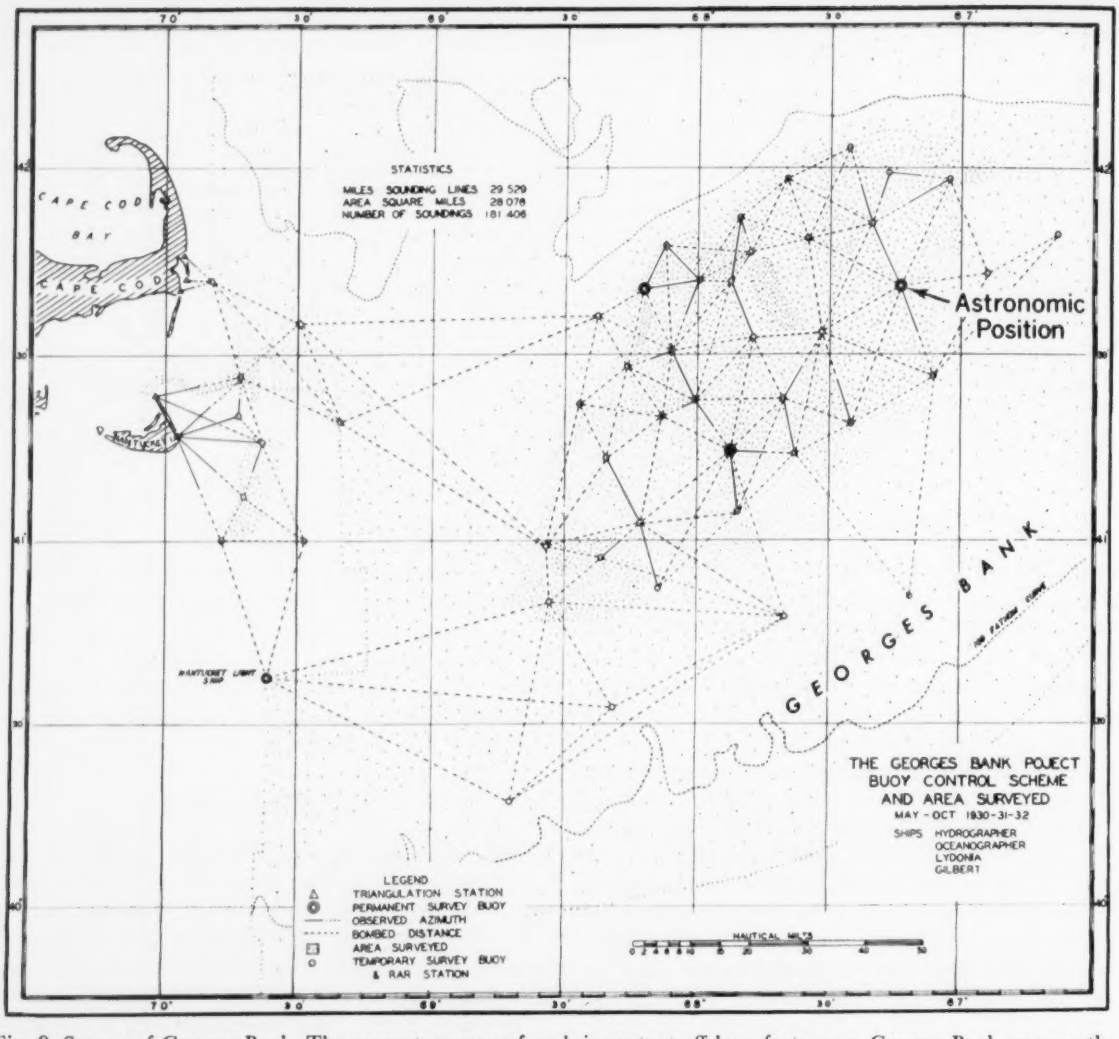


Fig. 9. Survey of Georges Bank. The accurate survey of such important offshore features as Georges Bank was greatly facilitated by modern methods of sounding and position determination.

throw the chart off balance. It is just as important to make proper and effective use of various forms of graphic presentation in the chart as it is to study the values of different methods of verbal or written presentation.

New Type of Nautical Chart

The most significant advance in nautical chart design since the introduction of colors was made in March 1939, when the Coast Survey published the first chart in which special emphasis was given to depth contours. The installation of echo-sounding apparatus on our naval and merchant vessels signaled the need for a new type of chart—one that would enable the navigator to utilize fully this new sounding technique for fixing his position at sea. It is axiomatic that the more faithfully the chart portrays the submarine relief, the greater will be its usefulness to the navigator. The answer was not found in an increase in the number of soundings charted; this was already a characteristic of the conventional chart. What was called for was a method that would utilize the wealth of submarine detail provided by modern hydrographic surveys and that would portray this detail in a simple and usable manner. The new chart was the result.

In this chart, depth contours, which are equivalent to land contours on a topographic map, are given special emphasis. In the drawing of the contours, full use is made of all the soundings obtained on the hydrographic survey. Characteristic features of the ocean bottom are brought into

prominence. These features are comparable to permanent landmarks and provide the navigator with a simple method for identifying his position by comparing a line of echo soundings with the charted depth contours.

Another significant innovation in nautical charting took place after World War II, when the United States Coast Guard established loran stations along our coasts as an aid to navigation. Lines of position in this electronic system are families of hyperbolic curves that do not lend themselves to ready plotting by the navigator, as is the case with a circular system such as shoran. To facilitate the navigator's use of this new aid, the Coast Survey, after experimenting with several methods of applying loran information to the charts, has evolved a form that combines the hydrographic information with the loran information, without confusion and in a manner that makes the chart of maximum use to the navigator. Loran charts now include coverage of the Atlantic, Gulf, and Pacific coasts.

Reproduction Process

On the reproduction side, we have indeed traveled far from the early days of copper engraving and plate printing. Charts of the earlier period were engraved entirely by hand—every line, every figure, and every letter. Many were artistic masterpieces. The fineness of detail that was made possible by this method of reproduction afforded the engraver an opportunity for artistic expression seldom equaled by any other method. These early charts were all black-and-white reproductions. Many were embellished with elaborate views of harbor entrances and headlands for the guidance of the mariner. One of the finest of these was the view of Anacapa Island, off the southern California coast (Fig. 10). This was engraved by James A. McNeill Whistler, who later achieved world renown as an artist. Whistler's stay in the Coast Survey was brief but hectic. He soon found the rules of the office too exacting for his artistic temperament, and he became a habitual latecomer. When chided about it in later years, his biographer tells us, he invariably replied: "It was not that I arrived too late in the morning, but the office opened up too early."

Photolithography paved the way for the introduction of colors and offset printing. Each rotary lithographic press in the Coast Survey today is capable of printing from 3000 to 5000 impressions an hour, as compared with the 100-a-day maximum that was possible with the older method of printing directly from engraved copper plates.

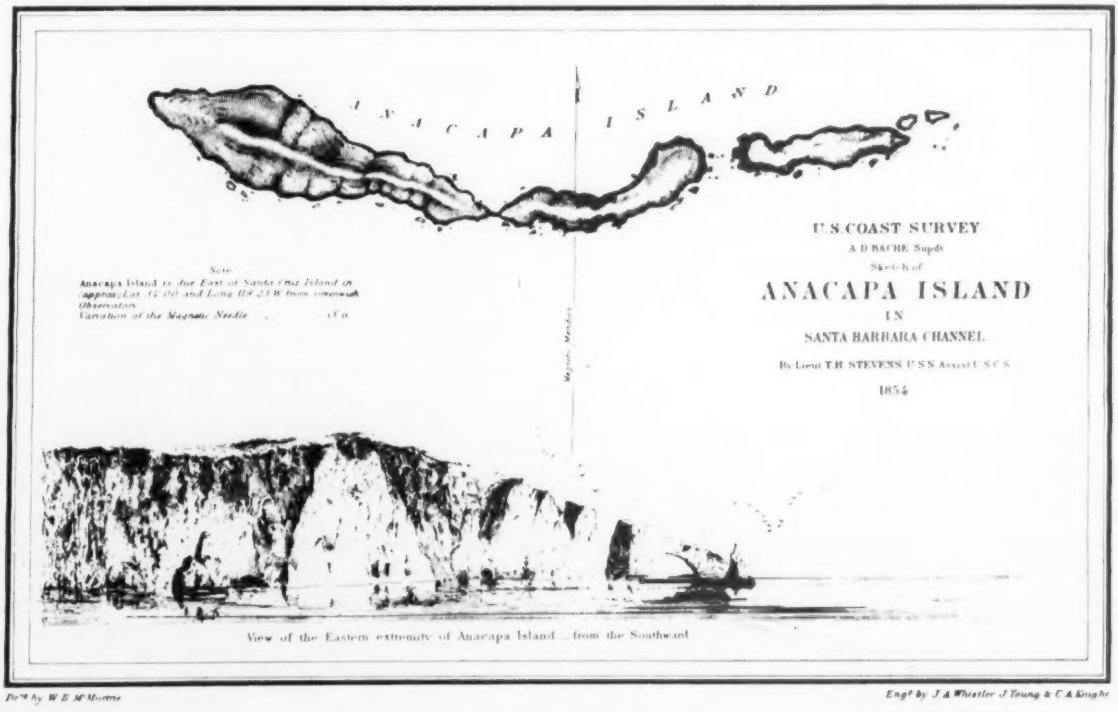

ANACAPA ISLAND
U.S COAST SURVEY
A D BACHE Supdt
Sketch of
ANACAPA ISLAND
IN
SANTA BARBARA CHANNEL
By Lieut T.H. STEVENS U.S.N. Assist U.S.C.S.
1854
View of the Eastern extremity of Anacapa Island from the Southward
Drn by W.E. McMurtrie
Engd by J.A. Whistler J. Young & C.A. Knight

Fig. 10. Chart of Anacapa Island, off the southern coast of California, engraved by James Whistler. The early charts were all in black and white. Elaborate views of headlands were sometimes included for the mariner's guidance.

Negative Engraving (Scribing)

The greatest single contribution the Survey has made in the reproduction process has been the development of negative engraving (now commonly referred to as "scribing"), at the turn of the century. This technique was first used as a more economical means of revising nautical charts. Revisions were applied directly to the wet-plate glass negatives by means of the conventional engraving needles then in use. Later, entire nautical charts were reproduced by this method. The compilation manuscript was photographed on glass negatives. These were then coated with an emulsion that was pervious to light and so afforded the engraver a facsimile of the manuscript. In 1935, the first engraving tool for specific use on glass negatives was designed. A special assignment for reproducing maps for the Tennessee Valley Authority gave impetus to the design of additional tools, and by 1940 all the basic instruments and techniques in universal use today had been perfected by the Survey. Both glass and plastic are now used for negative engraving.

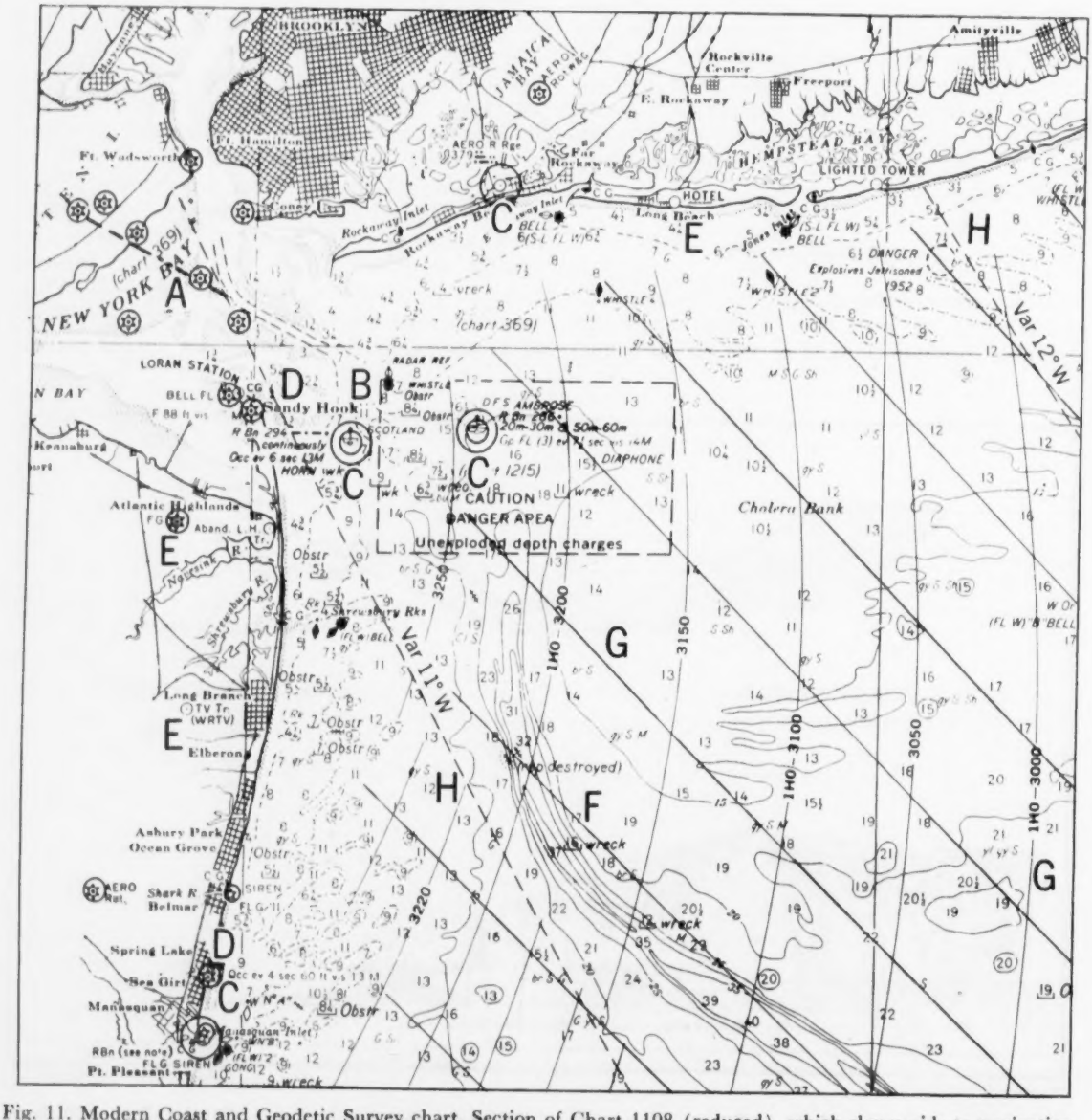


Fig. 11. Modern Coast and Geodetic Survey chart. Section of Chart 1108 (reduced), which shows aids to navigation for ships leaving or approaching New York Harbor.

In the Coast Survey, the direction is toward complete conversion from drafting to scribing of final copy, in both the chart production and reproduction stages, in order to realize all of the inherent quality and economy of the technique.

Aids for Safe Navigation

The modern nautical chart is thus a synthesis of the utilitarian and the artistic, suitable for meeting present-day demands for quantity and quality reproduction. It is a scientific achievement, the evolution of which has kept pace with the economic development of the nation and with the progress in science and engineering.

It is of interest to examine the latest Coast Survey chart of the approaches to New York Harbor [Chart No. 1108 (Fig. 11)] and to note the variety of data which the navigator has available to fix his position as he enters or leaves the metropolis. [Tints and colors (not shown in the illustration) to accentuate the land topography, shoal-water areas, depth contours, and so on, provide him with additional cartographic aids.] At *A*, he has a range for a line of position through Ambrose Channel. At *B*, he has a danger warning and channel marker —buoy with radar reflector by day and light of fixed characteristics by night. At *C*, he has radio beacons on the lightships and on shore for obtaining bearings by radio compass from the vessel. At *D*, he has the height and visibility of lights for determining position. At *E*, he has landmarks for taking angles and bearings—structures and natural objects by day and lights by night. At *F*, he has depth contours for use with an echo sounder. At *G*, he has loran lines of position for use with his loran receiver by day or night. At *H*, he has isogonic lines (lines of equal magnetic declination) to be applied to his magnetic compass.

One rightly wonders how the ancient mariner, without any of the modern navigational aids and contrivances, ever managed to reach his destination. Perhaps the answer is that very often he didn't!

The Future

Thus, the work which Thomas Jefferson launched a century and a half ago, when our coast line was confined to the Atlantic seaboard and to a small stretch along the Gulf of Mexico, has been extended through the years to keep pace with a developing and expanding America. The accession of Florida and the Pacific coast states, the annexation of Texas and the Hawaiian Islands, the purchase of Alaska, and the stewardship over the Philippines, all added to the charting responsibilities of the Coast and Geodetic Survey.

The Coast Survey views with gratification and pride the contributions it has made to the over-all program of surveying and charting our coastal regions. But its mission is not yet ended, nor will it ever be, as long as changes wrought by man and nature leave their impact on our shores. Change and not stability is the order of nature. This finds significant expression along the seacoast and the littoral. Breakwaters and jetties are built, channels and harbors are dredged, and new paths of commerce are opened. Rivers empty vast quantities of sediment near their mouths and thus build out the coastline and change the underwater configurations. Safe navigation depends on an accurate representation of all these changes on the published nautical chart.

Offshore, there are large areas, sparsely or inadequately surveyed, that require resurveys to insure the safety of submarine operations and to meet the exacting requirements of modern surface craft. As a by-product, these surveys of the continental shelves will increase in importance as technology advances and makes practicable the recovery of the resources the shelves are known to contain.

In Alaska, much surveying and charting remain to be done in support of the strategic defense of the Territory and in anticipation of increased commercial activity there.

As for the chart proper, it is fair to assume that its design has been stabilized, although not necessarily permanently fixed. Changes that do occur will be more in the techniques of compilation and reproduction than in the character of the finished chart. "Navigation with safety and assurance" has been the guiding principle of the Coast Survey in its program of nautical charting. This will continue to be its motto in the days ahead, and it will fashion its charts to meet the needs of maritime interests.

We who are privileged to look back on the first century and a half of the Survey's existence are justly proud of the record that has been written in its promotion of commerce, industry, and the national defense. Those who will have the task of carrying forward this work will derive inspiration from the great heritage of public service that has been bequeathed to them.

Sinkholes, Bottomless Lakes, and the Pecos River

E. R. HARRINGTON

Dr. Harrington, who is director of secondary education for the Albuquerque (New Mexico) Public Schools, received most of his scientific training at the University of New Mexico, the University of Southern California, and the Colorado School of Mines. For 25 years he has carried on a successful "one-school-system battle for education in science and mathematics." He is the author of several science textbooks and of numerous magazine articles. He has worked for the Hecla Mining Company, the Anaconda Mining Company, the Idaho Reclamation Service, and the New Mexico Institute of Mining and Technology; has taught civil engineering and geology at the University of New Mexico; and has served as consultant to the U.S. Air Force.

IN the summer of 1956 a cattleman near Vaughn, New Mexico, heard a great booming and roaring; the windows of the ranch house rattled. He ran outside, looked in the direction of the sound, and saw dust clouds rising from a rock flat a mile away. When he got there he found that surface rock layers, 100 yards across, had dropped 50 feet. Yesterday the flat had been topped by a horizontal layer of limestone; now the support had been withdrawn, and the surface rock had dropped, leaving a steep-sided hole to mark the spot. The horizontal rock stratum that had been yesterday's surface lay in jumbled pieces at the bottom. The cattleman had witnessed the birth of a new sinkhole on the Sacramento Plain.

Sinkholes on the Sacramento Plain

A neighbor of mine (*1*) owns a ranch on the Sacramento Plain (Fig. 1) that occupies much of the area between Vaughn and Roswell. He told me about the sink that formed on an adjacent ranch and asked: "Is something like that likely to happen somewhere on my ranch, even under my house?" It is a good question; a sinkhole could form anywhere on his ranch. One could form anywhere on the Sacramento Plain. The plain is a succession of rock layers belonging to what the geologists call the Permian "Red Beds." These beds have a combined thickness as great as 2000 feet, and at least one-third of the rocks are soluble in water. The Red Beds are sandstone, shale, limestone, gypsum, and halite (rock salt); the gypsum and the halite are soluble in water. When these soluble materials dissolve, caverns develop (Fig. 2). When the caverns collapse, a new sinkhole forms; thousands of such sinks dot the Sacramento Plain (Fig. 3).

Once the Sacramento Plain was a flat-topped plateau sloping gently to the east and south. Now it is a rolling, and sometimes ragged, surface marked by thousands of sinkholes—big, little, old, and recent. New sinks develop and the whole plain settles unevenly as the halite and gypsum are leached away. It takes a 700- or 800-foot well to reach water on most of the plain. The underground water surface (called the water table) slopes gently toward the Pecos River to the east. Rainfall upon the plain is only about 10 inches a year, and little of it is retained by the thin veneer of soil atop the rocks. Most of the water finds its way down through rock crevices, leaching out the gypsum and halite as it goes. Such seepage finally reaches the water table, and eventually much of it is discharged into the Pecos River through springs (Fig. 4). Little by little the whole plain is being lowered by solution of the soluble rocks beneath its surface. Occasionally a spectacular fall occurs, such as the rancher noted, but for the most part the action is imperceptible.

Through most of its length in New Mexico the Pecos River slices across the Sacramento Plain, in deep channel, 1000 feet below the plain's surface. Actually the river occupies several basins, connected by steep-sided canyons. The first such basin is at Santa Rosa, and it is clearly of solution origin; sinkholes have extended themselves until they have grown together to form a large solution basin. In the Roswell-Carlsbad section of the Pecos River, similar solution basins of the past have widened and lengthened to form an elongated north-south depression through which the river flows. Even the canyon sections of the Pecos River give evidence of following a series of collapsed sinks and trenches. Certainly the gypsum-halite sinks have had much to do with the development of the river.

Bottomless Lakes in the River Basins

Up on the Sacramento Plain, sinkholes may collapse several hundred feet without reaching the water table. In the Pecos River basins the water table is close to the surface. When a sinkhole develops in one of these basins the top stratum of rock falls into a cavern filled with water, and a lake or pond develops. Such lakes are rather deep; their sides are steep; boatmen and swimmers cannot touch bottom with oar or toe. The cowboy's lariat, with rock attached, often fails to find bottom in these ponds (Figs. 5 and 6). Hence, they are called *bottomless lakes* and are so designated in geologic reports (*2–5*).

To the casual observer the bottomless lakes in the Pecos basins are far more interesting than the wide and dry sinkholes so common on the high plains adjacent to the river. There is something intriguing about a small lake that has no visible or easily plumbed bottom. Back in 1891, Nettleton (*3*) investigated such lakes in the Roswell area. He received reports that 1200 feet of line had failed to reach bottom in one of the lakes. Nettleton's soundings found bottom at 48 feet, and he made the comment that he doubted that any of the lakes had depths in excess of 90 feet.

Still, fantastic stories are heard about the bottomless lakes. Some cowboys are said to have lowered an anvil on a mile of barbed wire without reaching the lake's bottom. I like this story better than all the others, since it implies such western ruggedness on the part of the investigators. I have also heard reports that the lakes' depths are inhabited by great turtles as large as washtubs, and that the turtles never come to the surface of the water. The last part of the statement is certainly true.

One persistent tale is that fish planted in one bottomless lake soon appear in an adjacent lake of the same kind. Meeks (*6*) a reputable geologist, widely known and respected in ground-water circles, has received numerous reports of this sort but attributes them to faulty vision or to exuberance acquired at some nearby saloon. The superintendent of the U.S. Fish Hatchery at Santa Rosa (*7*) has been planting fish in the bottomless lakes for more than 25 years without noting any authentic migration of fish from one lake to another.

Freeman and Mathers (*4*) tell of a controversy between two ranchers on the Sacramento Plain southwest of Santa Rosa. A sinkhole developed suddenly and became partially filled with water. Since water is very scarce up on the plain, both ranchers claimed the lake, finally going to court to settle it. However, before the decision was rendered, the water disappeared, leaving a dry hole.

During depression times a car-owner attempted to dispose of his automobile in order to collect the insurance. He ran the car off into one of the bottomless lakes, then reported the car stolen. Before he could make an insurance claim, however, a swimmer had seen his car on the bottom of the "bottomless" lake.

Pecos River and Sacramento Plain

In northern New Mexico the Sangre de Cristo Mountains rise to an altitude of more than 13,000 feet. These mountains are largely composed of old granites, quartzites, and other crystalline rocks of Pre-Cambrian age. In later Paleozoic times, during the Permian period, southeastern New Mexico and adjacent areas in Texas were occupied by an arm of the sea. The water in this sea-extension suffered continuous evaporation and periodic renewal, conditions producing a typical "evaporite" basin. Deposits of gypsum, sodium, and potassium salts were precipitated as brines of the basin became more concentrated from continual evaporation and restricted inflow of water. Occasionally, inflow into the evaporite basin, either from the sea or from the land, produced conditions suitable for sea-life and the deposition of limestone. A few fresh-water streams brought in sediments from the highlands to the north and west, depositing thin layers of sand, silt, and clay atop the beds of limestone, gypsum, and salt. Thus the Permian basin filled

Fig. 1. Map of New Mexico showing location of the Pecos River.

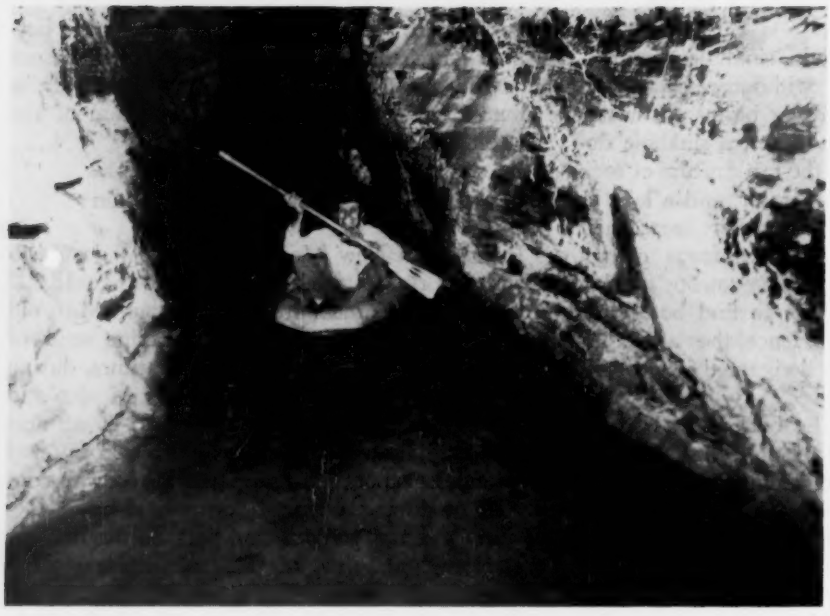


Fig. 2. A gypsum cavern near La Ventana, N.M., which has been explored for a distance of about ¼ mile. Depth of the water is greater than the length of the oar; therefore, the cavern is considered "bottomless."

with sediment, leaving a bewildering sequence of interbedded limestones, gypsums, sandstones, shales, and salts of various kinds. The stratigraphy of these deposits is complicated and will be left to the professionals in the field (*2, 5, 8–14*).

The early Pecos River flowed from the Sangre de Cristo Mountains, leaving the Pre-Cambrian crystalline complex, to move across the Sacramento Plain to the south (Fig. 7). The plain had emerged from the sea and had been uplifted more than 5000 feet. The Pecos River extended its channel southward across the plain by way of a series of collapsed channels and sinks. In summer the flow was small and the river quickly sank through the crevices in the rocks, reaching the water table several hundred feet below the plain's surface. As the water sank it dissolved some of the gypsum and salt; caverns developed and collapsed, and sinkholes formed. Surface drainage from the scant rainfall sent runoff into the sinkholes, and still greater solution took place in the soluble beds beneath.

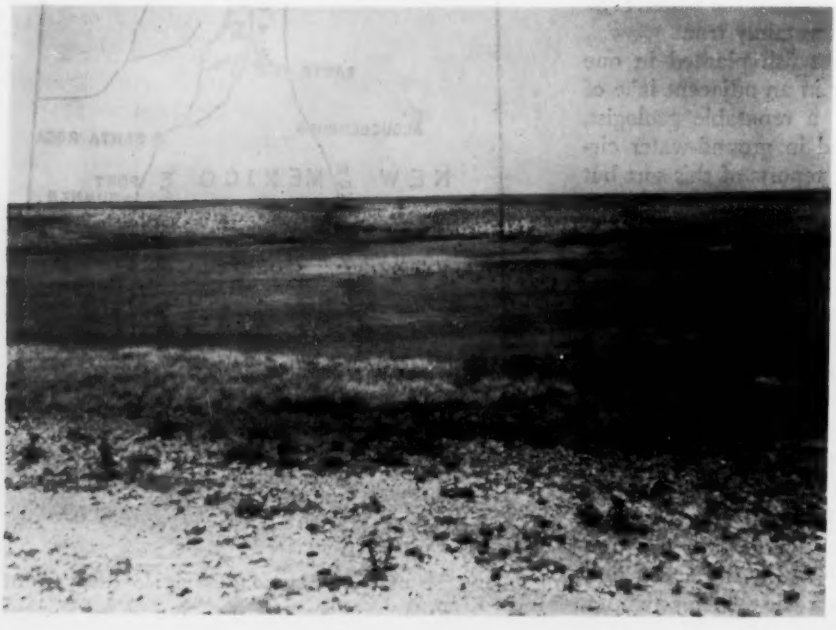


Fig. 3. A sinkhole in the Sacramento Plain between Vaughn and Roswell. Depth is approximately 75 feet.

Fig. 4. A large spring comes up in the bed of El Rito, a short tributary to the Pecos River near Santa Rosa. Discharge from the spring is about 3 cubic feet of water per second. This spring is about ½ mile from, and about 25 feet below, the Blue Hole shown in Fig. 5.

Fig. 5. Blue Hole, one of the "bottomless lakes" near Santa Rosa (actually about 80 feet deep). This is a flowing lake, discharging about 2 cubic feet of water per second.

Fig. 6. Hidden Lake, another of the "bottomless lakes" near Santa Rosa. The cap rock here is a thick layer of sandstone.

Fig. 7. The Pecos River in the Sangre de Cristo Mountains, about 10 miles from its source. As long as the river stays on the granite and the quartzite, it is a clear, swift mountain stream, as is shown here.

In flood times the Pecos River extended itself to the south from one sink to another, each subsidence adding to the length of the river. Eventually the river developed a narrow valley, consisting essentially of a series of collapsed channels and sinks several hundred feet beneath the general level of the Sacramento Plain.

In times of flood the water in the river is largely surface flow from the mountains to the north and west. In the more usual periods of low water there is little surface flow from the Sangre de Cristo Mountains and none from the Sacramento Plain. The water that falls upon the plain flows for a short distance to some rock crevice or sinkhole, there to seep downward to the water table several hundred feet below. The water table slopes toward the Pecos River and, in some places, discharges into it through springs. The sinkholes on the plain grow in depth and diameter and come together to form large composite sinks, several miles across and 500 feet or more in depth. Only a thin veneer of soil covers the surface of the plain. Some of this soil washes into the sinkholes, and a few of them "silt up" until they can hold a shallow pond of water. If the water becomes several feet deep, the water pressure may become great enough to reopen the silt-filled cracks in the sink's bottom, and when this happens the pond is quickly drained.

When the Pecos River leaves the Sangre de Cristo Mountains, it must flow 300 miles in New Mexico and an additional 300 miles in Texas before it reaches the Rio Grande, 400 miles from the Gulf of Mexico. Through long stretches the river will be dry, except in time of flood. What flow there is goes through underground channels. In some sections the water table intersects the valley floor, and a permanent stream flows; in other sections the water table drops below the valley floor, and the low water flow is then entirely underground.

Fifteen miles north of Santa Rosa, the Pecos River loses three-quarters of its surface flow in a distance of a few miles (*4*), only to get it back, with some additions, in and immediately below the Santa Rosa basin. A few miles below, the entire river goes underground in the McMillan Reservoir section, 20 miles north of Carlsbad (*9*), near the site of the Avalon Dam.

After each subterranean trip the Pecos River comes up with an increased mineral content. Above Santa Rosa the river carries about 131 parts per million of dissolved solids. Ten miles below Santa Rosa the mineral content has reached 1642 parts per million; between Roswell and Carlsbad, 3440 parts per million; and below Malaga Bend, near the Texas line, a high of 5120 parts per million.

From Malaga Bend on south, the mineral content of the Pecos River water is so high that it is unfit for irrigation use, unless it is diluted with considerable surface flood water from reservoirs. Within one 2-mile section of the Malaga Bend the river receives considerable seepage highly charged with sodium chloride. The springs are small but numerous, and some of them bring in water with a salt content greater than 100,000 parts per million. It is estimated that the Malaga Bend section of the river contributes 420 tons of soluble material daily, of which 370 tons is sodium chloride (*14*). When one considers that the river at this bend often carries less than 10 cubic feet of water per second, the seriousness of the salt problem becomes apparent. The salt seeps come into the river through a thick valley fill and cannot be diverted, since the entrance area is too great. Geologic exploration has revealed that almost all of the salt comes in along one "aquifer" or water-bearing layer. It is possible to move back some little distance from the river, sink wells into the saline aquifer, and pump it sufficiently to dry up the salt seeps that pour this sodium chloride into the Pecos. Plans are under way, at this writing, to install pumps to dewater the saline aquifer by pumping the water into a nearby dry lake, thus preventing added contamination to the Pecos River.

At the present time the mineral content of the Pecos River is such that 150 tons of solid material are removed each year from each square mile of the river's drainage area north of the Texas line (*10*). Morgan (*12*) points out that the volume of mineral salts removed in a million years at this rate would be sufficient to lower the river's watershed by 56 feet. He points out that far greater denudation has taken place, and he believes that, in past ages, still greater concentrations of minerals

Fig. 8. Gypsum sinkholes on the gypsum ridge on the east shore of McMillan Lake, 20 miles north of Carlsbad. When McMillan Lake covered this sink, the water leaked out so fast that people feared to approach the whirlpool in boats.

Fig. 9. Cracked gypsum ridge that forms the east shore of McMillan Lake on the Pecos River 20 miles north of Carlsbad. A wall was constructed in 1934 in an attempt to fence off the lake from this part of its shore.

Fig. 10. The large wall was built in 1934 in an attempt to fence off the lake from its leaky eastern shore. The wall is more than a mile long. Note the blanket of sediment that covers the floor of the reservoir. Even this has failed to stop the leaks in the reservoir's bottom.

were taken out by the river. This does appear to be possible. It is likely that the upstream areas, extensively leached for many centuries, might now produce less dissolved material than they did when more material was available. The great solution basins now occupied by the town of Santa Rosa and the wide valley of the Roswell-Carlsbad area indicate the locations where, in the past, solution was most active. Most of the soluble material has already been removed from the rock strata adjacent to the river. The present sources of mineral matter are the areas under the Sacramento Plain, back some distance from the river.

Leaky Reservoirs on the Pecos

Water is precious in the desert, and desperate efforts have been made to store it when it is available. Leaky reservoirs and dam sites have plagued the irrigation companies on the Pecos for 60 years. In 1891 the Avalon Dam was built (*15*). It was destroyed by a flood in 1904, the destruction being aided by solution cavities under, and adjacent to, the dam itself. The dam was rebuilt in 1907, and, while the site held this time, the reservoir did not (*16*). In 1904 a second structure, the McMillan Dam, was built upstream from the Avalon site. It was hoped that this reservoir would hold water better than the Avalon, but it was worse. When the impounded water rose to anything like the reservoir's capacity of 90,000 acre-feet, it overflowed into numerous gypsum sinks along the reservoir's eastern edge, and the storage water was quickly lost (Figs. 8 and 9).

Many efforts have been made to plug these gypsum sinks with various materials such as old automobile bodies, bales of hay, earth, soil-cement mixtures, swelling mixtures of soil and bran, and so forth. Losses from the McMillan Reservoir became greater each year. The best one could say for the reservoir was that it detained the flood water for a few days and reduced the flood danger downstream. In 1932 a new storage reservoir was built a few miles upstream from Fort Sumner, to take over the duties of the leaky Avalon and McMillan structures.

Still the people who had built the expensive McMillan Dam sought to salvage something on their investment. In 1934 the U.S. Bureau of Reclamation, aided by a Federal Emergency Relief Administration project, built a large wall, a mile long, along the east edge of McMillan Reservoir to "fence off" the reservoir from the most obvious of the gypsum sinks (Fig. 10). This helped a little, but the leakage was still great. The McMillan Lake has been reduced from its original capacity of 90,000 acre-feet of water to less than 37,000 acre-feet by the accumulation of a thick blanket of sediment. Even this cannot stop the leakage. The cavernous bottom of the reservoir continues to drink up most of the stored water.

And what about the future? It is likely that the pumping of salt from the saline aquifers in the Malaga Bend will make the natural flow of the Pecos River usable for irrigation. Construction of dams for flood-water storage will be attended by great likelihood of failure through leakage around the dams and through the bottoms of the reservoirs. Additional bottomless lakes will form in the basins of the Pecos River where the ground water is near the surface. Sinkholes will continue to develop, widen, and deepen on the Sacramento Plain. Such sinks will grow together to form larger sunken areas, and the whole plain will slowly settle through the coming ages.

What, then, about my neighbor? Should he fear that a sinkhole may suddenly develop beneath his ranch house? It is possible, of course, but the probability of its doing so in his lifetime is remote. His chances of injury from being kicked by his tame saddle horses or gored by his equally tame white-faced steers are much greater. Once he gave me a ride in his high-powered automobile. Since then I have figured that there are other catastrophes much more likely to befall him than the formation of a sinkhole under his ranch house!

References and Notes

1. W. Hardy, personal communication.
2. C. A. Fisher, *U.S. Geol. Survey Water Supply Paper* **158** (1906).
3. E. S. Nettleton, *Artesian and Underflow Investigations*. Report of the chief engineer, 52 Congress, 1 session; S. Exec. Doc. 41 (1892), pt. 2, pp. 14–15.
4. W. B. Freeman and J. G. Mathers, *U.S. Geol. Survey Water Supply Paper* **288** (1910).
5. A. G. Fiedler and S. Nye, *U.S. Geol. Survey Water Supply Paper* **639** (1933).
6. T. Meeks, personal communication.
7. J. R. Banner, personal communication.
8. W. T. Lee, *Science* **23**, 306 (1906).
9. ———, *U.S. Geol. Survey Bull.* **706**, 107 (1925).
10. N. H. Darton, *U.S. Geol. Survey Bull.* **794** (1928).
11. A. H. Morgan, *Trans. Am. Geophys. Union* (1941), pt. 3, p. 779.
12. ———, *Trans. Am. Geophys. Union* (1942), pt. 1, p. 27.
13. W. E. Hale, L. S. Hughes, E. R. Cox, U.S. Dept. Interior Water Resources Division (1954).
14. W. B. Lang, *Bull. Am. Assoc. Petroleum Geol.* **21**, 833 (1927).
15. J. Justin, *Trans. Am. Soc. Civil Engrs.* **87**, 1 (1924).
16. H. E. Robbins, regional director, U.S. Bureau of Reclamation, Region 5, Amarillo, Tex., personal letter, 6 Nov. 1951.

Some Implications of the Study of Animal Behavior

W. H. THORPE

Dr. Thorpe is a director of studies at Jesus College and lecturer in entomology at the University of Cambridge, England. He was Prather lecturer in biology at Harvard University in 1951–52. He has conducted research in entomology and animal behavior in Hawaii, Panama, Trinidad, Tanganyika, Kenya, Southern Rhodesia, and Florida. Five years ago he established the Madingley Ornithological Field Station of the Cambridge University department of zoology, where he now carries on his investigations of bird song. This article is based on his presidential address to the zoology section at the Sheffield meeting of the British Association for the Advancement of Science, August 1956, and is reprinted, by permission, from the September 1956 issue of The Advancement of Science.

THE modern school of animal behavior studies can, with some truth, be said to have begun with Darwin, for the publication—in 1872—of *The Expression of the Emotions in Man and Animals* was an important landmark and ultimately had a big influence. But its immediate effects were small, as were those of Spalding's admirable experiments on instinctive behavior in young chicks, published the same year; and the subject remained largely in the anecdotal phase until the later years of the century. Then the rise of the associationist or connectionist psychology in America, based on Thorndike's experiments with the "trial-and-error" escape of cats from his puzzle-boxes, and the development in Russia of the study of the conditioned reflex, led to a purely mechanistic-physiological view of animal behavior which found expression in the "behaviorism" of Watson and Loeb. Behaviorism had its merits and was in some degree a healthy reaction from the uncritical anecdotalism of earlier writers. But it was woefully inadequate as a general theory of animal behavior, and its life, in its original rather crude form, was short. In its turn it gave rise to revulsion on the part of those who were studying the more complex aspects of behavior, such as visual perception, where the inadequacies of behaviorism and simple associationist ideas were startlingly apparent. So it was that a group of German psychologists and sensory physiologists—Wertheimer, Köhler, and Koffka—gave the pendulum a swing in the other direction with the development of the Gestalt psychology.

What was happening in England while the pendulum was thus oscillating in other parts of the world? The story of English work in animal behavior is, I think, very characteristic of the English mentality. There was a cautious, conservative unwillingness to be rushed from one extreme to another, which can be found in so many branches of English life and thought. Spalding had unfortunately died young, and the characteristically English students of animal behavior succeeding him were Lloyd Morgan and Hobhouse. These two had indeed reacted from the uncritical credulity of Romanes but not with any extreme swing in the other direction; and I think it is instructive to look at the animal through their spectacles. Both Lloyd Morgan and Hobhouse were primarily philosophers, and their deservedly great reputation rests principally on their philosophical work. But they were both men of great general learning, having a sympathetic understanding of animals, combined with a genuine interest in experiment. While giving full weight to field observation and anecdote, where reliable, they both saw that the urgent problems could be solved only by experimental investigation. I intend to take Lloyd Morgan as the representative of the two and compare his attitude to animal nature with our own, more than half a century later.

Pioneer in Behavior Study

Lloyd Morgan was the real founder of experimental animal psychology. His attitude to animal nature can best be made clear by considering his belief in the three levels of mind (assuming that the instinctive was a level of mind and not only a level of body behavior). These three levels he called percipient, perceptive, and reflective, and he regarded them as associated, respectively, with the subconscious, conscious, and self-conscious mind. Percipience he regarded as the equivalent of sense awareness; animals having nothing more than sense awareness would be percipient, as babies at birth or

perhaps only before birth. He says: "Bottom-level minds, if such there be, are percipient only, having sense awareness and no more. Middle-level minds are perceptive and percipient, while top-level minds are reflective, perceptive and percipient." Thus, in contrast to C. Sherrington (*1*), who spoke of instinct as implying some slight degree of anticipation, Lloyd Morgan regards the subconscious mind of instinct as mind at the percipient level of mental development, having no sense of past or future. Conscious mind is perceptive, and this betokens expectation based *on what has been learned on prior occasions.* The reflective mind is regarded as self-conscious in the sense of embracing, to some degree at least, both past and future in relation to an awareness of self. So he would see in "trial-and-error" (an expression which, incidentally, we owe to him) nothing more than unreflective "fore-experience" or simple expectation of the future without a fore-plan for it; whereas trial-and-error when it becomes reflective leads to a plan for the future also. This "plan" is what W. Köhler calls *insight.* The "plan" may be too elementary or too incomplete to cope with a given situation, in which case the only course open to the animal is to continue with trial-and-error, at any rate for the time being. But if the external situation is very simple, or if the plan becomes sufficiently articulate and complex, then it may give rise to the phenomenon known as latent learning or insight learning, and so the plan becomes open to experimental investigation. Lloyd Morgan believed emphatically that the study of animal behavior can give the investigator real knowledge of the nature of mental processes in animals, and that these mental processes play their part in controlling behavior. These mental events he regarded as something different from physical events. In this he was a psychologist of the old school, making quite clear his disagreement with any type of theory which looked upon animal behavior as explicable in terms of physiological mechanism and nothing more. Yet it is instructive to remember that Lloyd Morgan (*2*), far from beating swords into plowshares, successfully beat Occam's razor into a canon and thereby provided the behaviorists with their chief weapon. That Lloyd Morgan used it himself with great effect combined with circumspection hardly needs saying. Whether the behaviorists used it justifiably or wisely is another matter; it has certainly been of enormous value to comparative behavior studies in general and indeed in many other fields of science also.

This question of the relation between mechanism and mental events is one which has again come strongly to the fore as a result of the development of electronic machines, which are not only conditionable but which can even display behavior superficially characteristic of latent learning and of insight learning; and, of course, the postulation and investigation of mechanism is an essential method of approach for biologists. But this does not mean that the mechanistic hypothesis is conceivable as a fundamental explanatory principle in a biological philosophy, and it was this that Lloyd Morgan was seeking. As J. H. Woodger (*3*) has pointed out, we may talk of purposes in animals as in human beings, and we may, and nearly all of us do, think that something like purpose—at any rate in some animals—is the cause of at least the "higher" types of learning. But it is extremely difficult, at the levels with which we usually deal, as biologists, to prove the causal effectiveness of purpose in the sense that all other possible explanations are excluded. It is always possible to defend microscopic mechanism in principle, if you wish to do so, by making your mechanism complicated enough and by postulating enough submechanisms to meet all contingencies. This game of making hypothetical submechanisms can be carried on a long way and is at first sight very convincing, although there is ultimately a limit to it, for if we go on making our supposed mechanisms smaller and smaller, we come eventually to the subatomic level at which the concepts of form and even the idea of occupation of space lose all meaning, and the idea of physical causation has likewise disappeared. This, however, is fortunately far beyond the level with which biologists have, as yet, to concern themselves; and the level of micromechanisms which biologists are tempted to regard as plausible can often be neither refuted nor verified. But, as W. E. Agar says (*4*), anyone who accepts this kind of explanation as by hypothesis responsible for the whole of animal behavior, must also, of course, accept it for his own consciously purposed acts; unless he holds dogmatically that there are factors in human behavior which are different not only in degree but in kind from the factors determining the acts of lower organisms. Nevertheless, as biologists we are entitled to claim that when we speak of animal behavior as appearing, shall we say, expectant or anticipatory, we are, for the time being, speaking of a mechanism which acts as if it were expectant or anticipatory, and reserving judgment on more fundamental issues. Biologists may be justified in this attitude only as long as they realize that this is a linguistic device and not a philosophical position. Thus Lloyd Morgan, by avoiding the extreme views of both those camps which were warring on the other side of the Channel and across the Atlantic, achieved a general attitude toward animal behavior and experi-

ment thereon which is striking for its sanity and balance. Study of it can yield much profit today.

But let us return to consideration of the position on the Continent. The coming of the school of behavior study to which the name *Ethology* was first applied in 1935 was an expression of the reaction of zoologists against two extreme camps: those of the old anecdotal comparative psychology, on the one hand, and the rigid Russian reflexology, on the other. The old subjective animal psychology was in danger of having us suppose, for instance, that a bird building its nest for the first time foresees the young it will be feeding some weeks later; that the salmon returning to the river of its birth is looking forward to the spawning period. So it was a natural and, indeed, an inevitable step for naturalists to get back once again to the descriptive, empirical, objective phase and to recommence by observing, recording, and analyzing the animal's behavior experimentally—first in as natural a situation as possible and then with simple experimental controls. And here we see how Darwin was in fact a forerunner of modern ethology, for in his *The Expression of the Emotions in Man and Animals* he is concerned not so much with the emotions as they are supposed to be felt by the animal (though this is implied) as with the similarities of emotional expression and behavior in widely separated groups of animals.

New Approach to Animal Behavior

What, then, was new in the approach to animal behavior started, and to a large extent characterized, by the early papers of Konrad Lorenz? First as to technique: as complete an inventory as possible must be made of the whole system of actions of the animal in its normal environment; and such special techniques as have been developed are primarily those which aid and make more precise this primary observation—the technique of keeping animals under observation yet with the minimum of interference; the technique of marking individuals so that they can be recognized throughout large stretches of their lives; and the techniques which aid in the recording of their consequent actions and behavior. Ethology is thus essentially a naturalist's approach, and it first emphasized and brought under experimental study stereotyped, relatively rigid species-characteristic actions (for example, the web-spinning of spiders, the nest-building of solitary and social wasps). Second, it drew attention to the evidence that such actions are governed in some degree by an internal drive, a point which most zoologists who failed to remain field naturalists (that is, most zoologists!) seem almost completely to have forgotten. Third, it produced a hypothesis to account for this internal drive which allowed scope for the action of hormones and elaborated it into a hierarchical scheme of organization.

This internal drive is of the very essence of the meaning of the word *instinct*. Most of the workers who had seriously considered the subject prior to 1935 uttered vague generalities about "tension," "nervous energy," and so forth, which were of little use either as explanatory concepts or as guides for future research. Lorenz (*5*), in papers which appeared between 1935 and 1939, and Karl Lashley (*6*), in a paper dated 1938, realized independently that the more promising way of tackling this problem of the internal drive behind instinctive behavior would be to study not actually the drive itself but rather the internal system of coordination of special behavior patterns, on the one hand, and the special sensory mechanisms, on the other. They saw in fact that the complex and stereotyped action-system and its coordinating mechanisms might be more fundamental to the subject than the question of drive, and they suggested that a study of these mechanisms might eventually throw further light on the problems of drive and motivation. Such an approach was not new, for human psychologists [notably R. S. Woodworth (*7*)] had pointed out that habit mechanisms, at any rate in human beings, may become drives and had implied that habit and instinct had therefore much in common, and that in both cases the coordinating mechanism of the behavior pattern might itself be producing the drive. One has only to extend this concept from the learned behavior, which in human beings we call habits, to the inborn, instinctive actions of animals to arrive at the first essential idea of the Lorenz-Lashley scheme. Looked at physiologically in this way, drives are seen to be nothing more than expressions of the activity of specific mechanisms, and the general theory which Lorenz built on this quickly provided a more comprehensive framework for the description and further study of instinctive behavior than any which had preceded it.

The new approach resolved many of the earlier difficulties. It emphasized that there are some elements of what we call instinctive behavior which are extremely rigid and indeed, in their way, as constant as anatomical structures and therefore potentially just as valuable for the study of evolutionary relationships. It was also pointed out by Lorenz that where, as is so often the case, such very rigid action-patterns constitute an end-point or climax of either a major or a minor chain of instinctive behavior, they are in some sense consummatory in that they effect the release of the tension

which has, up to that point, been activating the instinct in question. Such *consummatory acts* are familiar to all. One need only mention the elaborate nesting and egg-laying behavior of the solitary wasps, the stereotyped sexual displays of birds, or the elaborate and apparently inborn movements of innumerable predatory animals, whether fish, birds, or invertebrates, by which a particular kind of prey is successfully caught. This view, then, involves the idea of the coordination mechanism of the fixed consummatory act, giving rise to the tension which activates the instinct, until it finds relief in discharge of the act in the appropriate situation. As long as the act remains undischarged, the animals continue to show an introductory phase comprising more or less complex searching activities, the appetitive behavior. This behavior is such that there is a reasonably good chance of its bringing the animal, before long, into the appropriate situation for the consummatory act to be performed. The animal is *apparently* looking for its prey, *apparently* searching for a nest site or nesting materials, or else is going through a series of actions, such as those employed in nest-making in insects and birds, which will in due course lead on to the completion of the particular chain of instinctive behavior. This distinction into appetitive behavior and consummatory act was not in itself new. Sherrington and others had used much the same terms in much the same sense; but it was important just at this juncture because it resolved the apparent disagreement of previous workers as to the relative flexibility and rigidity of instinct. For by definition the consummatory act now became the characteristically fixed part of the behavior—the fixed-action-pattern, as it is now called —and the preliminary or searching behavior was regarded as the flexible part, where learning ability and, perhaps, "intelligence" were able to show themselves. Another immediate advantage of this scheme lay in its apparent avoidance of the vitalistic approach, for the objective of the animals is now no longer seen as the attainment of the final biological goal or result (which it is, of course, inconceivable, in most cases, that it could foresee), but rather the performance of the consummatory act itself, which can be achieved only as a result of finding the appropriate environmental pattern of stimulation, the *releaser,* which can "unlock" the *innate releasive mechanism* and so allow the act to proceed. The new theory substituted a physiologically reasonable system for a largely untenable vitalistic one, and this was another reason why it has ever since yielded such good dividends in promoting research.

While the idea of a relatively rigid consummatory act is thus a theoretically sound one, and while the separation into two categories probably continues to be as useful now as it has ever been, recent researches—particularly those of the last decade or so—have made it abundantly clear that the distinction is not hard and fast. For instance, much appetitive behavior contains rigid consummatory acts, of what might be termed a minor grade, and many examples are now known in which appetitive behavior and consummatory act vary greatly in degree of rigidity and flexibility. Both may show some evidence of internal activation; both may be stereotyped to some degree and show some rigidity, and both may be to some extent flexible. I shall return to this subject shortly and give some examples to illustrate the point; suffice it to say now that the characteristic instances of flexible appetitive behavior and rigid consummatory act can be regarded as the two ends of a series.

So to some extent the original picture drawn by Lorenz, which was so attractive in its clarity and simplicity, has, as always seems to happen in scientific research, been complicated and somewhat blurred by the detail since added to the picture. And this in its turn has important implications for our ideas of animal nature. If the internal organization of the consummatory act is not now seen to be as rigid and stereotyped as was formerly thought, it becomes harder to envisage it as providing the specific internal motivation for behavior which Lorenz supposed. Besides "seeking" to discharge its fixed-action-patterns and so relieve the instinctive "tension" accumulating around the mechanism, there is now evidence that some of the searching is an attempt to find a key environmental situation. Perhaps there is also some real, though very limited, element of purposiveness in the search for a satisfying situation. Actions are not always brought to cessation by exhaustion of internal drives or by the cessation of the eliciting stimulus. On the contrary, there are external situations which, instead of, or in addition to, acting as releasers for the next phase of behavior, serve to bring the previous phase to a close. In this case they must be effective in stopping a piece of behavior even when the original eliciting stimulus is still present. They are thus *consummatory stimuli* or consummatory situations, or, in simple English, *goals.* Thus we now see that the goal is not always the performance of an action; it may sometimes be the perception of an environmental situation. The attainment of such a situation may in fact be as effective in bringing a particular piece of behavior to a close as is the satisfaction of a phys-

iological need or exhaustion of the internal drive behind the fixed-action-pattern or consummatory act.

Interaction of Learning and Instinct

The original instinct theory of Lorenz thus gave a picture of the animal as "searching," by means of a series of stereotyped orientation mechanisms, for the situations which would release the consummatory acts. The recognition of these situations was largely inborn, though of course it could be modified to a greater or lesser extent by reflex conditioning or other forms of learning, and the act itself was the true goal of the behavior. When the act is at last performed or, as we would now add, the consummatory situation at last reached, that particular behavior chain is for the time being completed, and so the episode is brought to a close. It may be a final conclusion, as in such behavior as the cocoon-spinning of Lepidoptera, where, once the highly elaborate series of acts has been accomplished, a part of the life cycle has been achieved once and for all and will never be repeated by the individual; or, on the other hand, it may be a type of behavior which is repeated constantly during the whole life—as feeding or mating, for instance—and the whole system may be due for reactivation in a period of minutes, hours, or days by hormonal control internally aroused or by other internal complexes of stimulation. We know that, valuable as is this picture, the account it gives is not complete.

These newer theories of animal behavior have also done valuable service in emphasizing the significance of the interaction of learning and instinct in animals. I said just now that learning abilities play their part particularly in the flexible appetitive behavior. Very many higher animals can learn to adapt their hunting methods, at least in some degree, to the particular circumstances which they encounter and to the particular methods of avoiding action employed by the prey which they find. In contrast it may be very difficult or impossible for an animal to adapt its cocoon-building or mating behavior even after repeated lack of success. But if the two categories of appetitive behavior and consummatory act are not as sharply defined as we thought, then we must be prepared to find (as indeed we do find) that some appetitive behavior is more rigid than we should have originally expected and some consummatory acts more flexible. And this conclusion has brought into prominence the importance of the type of learning known as imprinting—not really a new category of learning, but merely learning ability restricted to a particular and perhaps very short period of the animal's life and orientated by innate predisposition to a particular circumstance or in a particular direction; as when an insect or an intertidal mollusk learns a particular diurnal rhythm of behavior from its first day's experience of it, or when a young bird learns the characteristic appearance of the species by following its own parent or learns the niceties of its specific song by imitating its neighbors during its first few days of singing in a territory. This kind of learning is important when we are thinking of the implications of modern behavior studies for our views on animal nature. Finally, it has been shown that highly elaborate learning processes may be displayed by some animals possessing nervous centers far inferior in mass and complexity of structure to the mammalian cortex. Not so long ago, for instance, insight and insight learning were assumed to be the prerogative of the highest mammals only, and it was thought that only nervous structures of the complexity, mass, and elaboration of the mammalian cortex could possibly provide the mechanisms necessary for the production of such apparently intelligent responses. Now we find that behavior giving good evidence of insight is found not merely in mammals but also in birds, fish, some arthropods, and perhaps in organisms even lower in the zoological scale. In fact our present knowledge of complexities of perceptual organization in the homing bird and the foraging honeybee have made it clear that in certain limited respects some of these creatures rival all but the highest mammals, if indeed they are inferior even to them. So it follows that our ideas about the mechanism of brain action may need a drastic revision as a result of some of the recent studies of submammalian and invertebrate behavior.

"Insight" in the Hive

Let us now consider actual examples of recent research bearing upon some of these crucial questions of the goal of the animal, the perception of complex releasers, and the level of integration achieved. First, let it be said that it is quite difficult to find an example of a metazoan animal whose sense organs and responses are such that one is convinced that it is, to use Lloyd Morgan's phrase, percipient only—that is, responding to crude sense-data and not in fact displaying some more or less elaborate organization of perceptual relations similar to what we usually regard as insight. Until a few years ago the division of labor among workers

of the honey bee was thought to be based upon the physiological states of the insects concerned, and not to be directly correlated with the needs of the colony as a whole. Thus it was thought that the newly emerged worker was compelled, by physiological conditions arising from the age and state of its organs of internal secretion and its nutrition, to go through the series of actions appropriate to the cleaning out and preparation of cells in the hive, whether this particular work was required by the hive at that time or not. If it was unable to find a place for this particular activity, then it was forced to remain idle until the development of its glandular mechanisms rendered it capable of the next series of activities, which might, for instance, be comb-building. So it was thought that each individual went through an inevitable and ordered series of actions, such that by the time the first half of its life was completed it would have done its share of all the duties which had to be done inside the hive, its final occupation (marking the end of its life as an indoor bee) being that of acting as a guard bee at the entrance. After that, it becomes an outdoor bee, and a similar and further series of actions appropriate to the outdoor life, such as foraging, are then gone through, physiologically conditioned as before. While it may be that the *average* worker bee may spend the greater part of its time in some such sequence of actions, it is now clear, from the work of M. Lindauer (*8*), that the program of work carried out by the individual is not, in fact, primarily or exclusively determined by the physiological state of the insect but is dictated by the needs of the colony as a whole. Moreover, it seems clear that regulation by the colony's needs must be through an elaborate series of releasers—mostly proprioceptive, though no doubt chemical releasers are also very important. Thus the individual cell-building worker seldom or never itself carries out in complete, correct, and uninterrupted sequence the whole process of cell construction. Yet it performs every action of this sequence innumerable times, as and where required. It may, for instance, start a cell with the wax produced from its own glands, which it has manipulated. It may then put the finishing touches to another cell, using wax supplied by another bee, or perhaps a bit of light capping taken and molded from a cell temporarily out of use. Then again—sometimes using wax from another worker, sometimes its own—it will perform the laborious and delicate tasks of planing and polishing to produce the thin cell walls—all this in the intervals of performing duties of entirely different kinds, such as feeding larvae, storing nectar, or attending the queen. Much of the time it may not be nearly as active as the legend of the "busy bee" might lead us to expect. In fact it may apparently waste a great deal of energy just wandering about the hive investigating this or that in an apparently random and useless manner, but perhaps all the while accumulating "knowledge" of the situation in various parts of the hive and of the places where jobs of various kinds may now or later be available for the doing (*9*). But whatever be the ultimate explanation of this new aspect of the behavior, we seem quite safe in concluding that the achievement of consummatory acts in the original Lorenzian sense cannot possibly be the sole mechanism whereby the instinctive behavior of the worker honeybee is taken step by step along its appropriate course. At least as important, and perhaps far more important, is the perception (and organization of perception) of the situation within the hive—perceptions which obviously are themselves goals quite as much as are any of the stereotyped actions which have been described. So here again we must speak of consummatory situations or consummatory stimuli, just as much as of consummatory acts.

Nest-Building and Perceptiveness

The same is probably true in lesser or equal degree of many behavior chains which involve the construction of elaborate nests. When such a bird as the longtailed tit finishes its wonderfully elaborate domed nest, properly lichened, lined, and with a perfectly constructed entrance, a great variety of different stereotyped acts must have been employed, and probably a still greater variety of consummatory stimuli perceived. In this particular case at least 14 different acts or combinations of acts have been involved, but even with all these the bird would, it seems, fail to produce a complete and perfect nest unless it had some "conception" of what the structure should look like and some "conception" that the addition of moss or a piece of lichen here and there will be a step toward the ideal pattern, and that other pieces here and there would detract from it. The bird does not in fact go on building up the top of the nest indefinitely; it does not build downward over adjacent twigs or cover them with lichen; it does not close up the entrance hole from outside—in other words, its actions are directional. It recognizes when to stop and shows evidence of having some very short-term purposiveness (not, of course, that it can possibly know, at the time of first building, what the ultimate objective of its actions must be), but purposiveness to the extent of being able to take the next minute step toward the completion of a

dimly "seen" pattern of nest structure. It is very difficult to distinguish in animals between directiveness, which is the property of all well-designed machines, and true purposiveness in the sense in which we use the word when referring to our own purposive behavior. But it does seem to me that at present the only reasonable working hypothesis is that an extremely short-term purposiveness, a foresight of one or two tiny moves ahead, is being shown by some animals in this kind of situation (*10*), and this is an important conclusion for Lloyd Morgan's position, since, as we have seen, he postulated that mental activity, at least on the first occasion in the life cycle on which a sequence of instinctive actions is performed, is percipient only. If we are right, now, it contains, as Sherrington also concluded, something more—a germ of perceptiveness.

Communication in Bees

The elaborate organization of sense perceptions and the nice interlacement of learned and instinctive behavior must be evident to anyone who thinks about the now widely familiar work of von Frisch on the transmission of information about the direction and distance of a food source from a foraging worker bee to another worker in the hive. We now know, for instance, that the performance of a figure-of-eight dance must be dependent upon an inborn behavior pattern of extraordinary complexity, since it is hardly conceivable that the individual worker bee can have the opportunity to learn the relation between the general idea "position of food source" and the orientation of the dance on the surface of the comb within the dark hive—another beautiful example of the coordination of inborn and learned behavior, producing in this case a language of remarkable economy and efficiency for the purpose in hand. Some interpretation of the dance must also be inborn, but it appears that young bees are unable to forage successfully until they have first gone through a learning process and reached a certain degree of perfection of dance-following within the hive. It appears that very few young bees leave the hive on independent excursions, but nearly all get their first detailed foraging experience as a result of, themselves, following a dance; for although the pattern of actions of the figure-of-eight dance and its correct interpretation are both inborn, following the dance needs special practice. Inexperienced bees often find difficulty in turning sufficiently rapidly and so may appear clumsy and confused at the sharp turns of the leader. Also, since their efforts are still somewhat spasmodic, they are rather easily interrupted by the other workers crowding round, and so may have to wait until they have the luck to follow a dancer in a region of the hive where there is not too great a crowd.

Still more astonishing, perhaps, are the recent developments in our knowledge—again due primarily to Lindauer (*11*)—of the methods by which scout bees choose new sites for the swarm to go to. Communication is in this case also effected by dancing, which now takes place on the surface of the swarm rather than on the comb. Since the new sites sought for are always some distance away, the dance is always of the figure-of-eight type, never the round dance, which refers only to near objectives. When the time comes for swarming (that is, when the hive is overcrowded with provisions and sealed brood so that the foragers can no longer process nectar), the workers are forced to abandon their normal activities. Most of them remain unemployed in the hive, but some of those who are particularly experienced become scout bees and fly out to look for a new home. These scout bees are apparently able to make an absolute estimate of the "quality" of the sites they discover (presumably a synthesis of the properties of shelter, accessibility, ventilation, and so forth) and they communicate this information about suitability by the vivacity of their dancing. Those that dance with greater vivacity are more likely to secure an "audience," and so there will be a tendency to concentrate interest from the beginning on those dancers which are communicating information about the best dwelling places. Scout bees which may, at first, advocate inferior dwelling sites may "change their minds" if their colleagues have better homes to offer, and so, after a longer or shorter period, virtual unanimity is secured, whereupon the swarm departs to its new home. Thus, the dances of the scout bees on the surface of the swarm indicate distance, direction, and suitability of site. This estimate of suitability must, in some obscure way, be an absolute one, since it has to be appreciated in competition with the similar estimate of other sites made by the other scout bees. How this complex estimation of a quality of a site can be standardized and expressed consistently as duration of "bouts of dancing" is at present exceedingly difficult to understand.

Bird Navigation

The sun-orientation mechanism of birds is now well known from G. V. T. Matthews' recent book (*12*). In its correlation between inborn faculties and experience it is remarkably similar to that of the honey bee. In both there is appreciation of

the position and movement of the sun, presumably inborn, together with an accurate internal clock. In both there is the innate ability to relate a given direction to the space-time standards innately provided and, moreover, to relate the observation of these standards to the knowledge of general topography and special landmarks gained from individual experience—although bees seem unable to do the reverse and relate a route flown under overcast skies, entirely by landmarks, with a particular direction. In both bird and bee there is also an appreciation of the relations between the position of a light source and the direction of movement (foraging flight, migration flight, homing flight), but the honey bee does even better than the bird in two respects. First, it must transpose between sun-direction and gravity-direction, and, second, it must be able to transmit information by transposition between the direction of the foraging flight and the straight run of the dance. As far as we know, birds do not need to transmit such information and so lack these additional faculties which the honey bee possesses.

These and similar studies of orientation and perceptual organization constitute some of the most startling recent developments of ethology. Naturalists of 50 years and more ago were deeply impressed by the complexity of the action-patterns of instincts. But they had hardly realized that innate *perceptual* organization must be no less complex, and the sensitivity and fineness of adjustment characteristic of many organs of special sense, as now revealed by sensory physiologists and by ethologists, was quite undreamt of.

The latest example of this is the experimental demonstration by P. Sauer and E. Sauer (*13*) that certain warblers that migrate by night (for example, blackcap and garden warbler) can maintain orientation only if they have a clear view of the starlit sky. They seem able to do this even if they have been hand-reared and have never seen the sky prior to the experiment, the present implication being that they have an innate releasive mechanism attuned to certain features of the seasonal star pattern of the Northern Hemisphere.

The innate coding of such organizations in germ plasm and higher nervous centers poses even tougher problems for geneticist and neurologist than does the existence of fixed-action-patterns. With the latter there is always the possibility that proprioceptive feedback or reafference can, on the chain reflex principle, provide at least some of the explanation, whereas in much of the former this is hardly conceivable.

Studies of Bird Song

Another example of the ability to perceive complex patterns and, further, to develop complex actions by elaborate learning processes by, so to speak, building upon the inborn recognition of such patterns, is provided by the studies of bird song which we have been carrying out for some years now at the Madingley Ornithological Field Station of the Cambridge University department of zoology (*14*). Here the pattern perceived is a temporal pattern of sound, and the complex actions guided by it, and developed therefrom, are the actions of singing the song. Although call notes are usually stereotyped and inborn, it has long been suspected that learning plays some part in the production of the full song of songbirds, for the imitative abilities of birds such as the bullfinch, starling, mockingbird, and parrot are known to all. Nevertheless, in some species (for example, the corn bunting, reed bunting, and some species of warbler) the normal characteristic full song is entirely inborn. More interesting, for present purposes, are those species, such as the chaffinch, linnet, and yellow bunting, in which the basic pattern of the song is innate, but all the fine detail and much of the pitch and rhythm have to be learned. Thus the normal chaffinch song consists of three more or less well marked phrases, ending in a final flourish. If, now, one takes young chaffinches from the nest and rears them by hand, individually, in a soundproof room, or at least out of hearing of all chaffinch song, there is no longer any division into separate phrases, although the song is about the right length and there is a tendency for some birds to conclude their utterance with a single, simple note of higher pitch than the rest—a sort of squeak. This, then, seems to represent the inborn inherited basis of the chaffinch song. If, however, after rearing such birds through babyhood, we keep two or more of them together (although still under conditions such that they never have the opportunity to hear experienced chaffinches), a very big difference becomes apparent when they commence singing in earnest, at about the age of 9 months. Although their inborn songs are so simple, yet the attempt to sing these in company provides a mutual stimulation which encourages the production of complexity. As a result of mutual imitation, each of such birds or groups of birds will build up a distinctive community pattern. Many experiments have now shown that there is a period of about 6 weeks' duration or less, at about the 11th month of life (when the bird is for the first time in its life in the physiological

state appropriate for territorial song), when the full song is learned. Once this time has passed, the song is fixed for life, and it does not matter to how much wild chaffinch song such birds are now exposed—year after year they will sing only the song which they worked out for themselves as youngsters. These and many other similar experiments make it clear what is happening in the wild. Young chaffinches must certainly learn some details of song from their parents or other adults in the first few weeks of life. For instance, they learn at this stage that the song "should" be divided into two or three phrases and "should" end with a more or less elaborate flourish. But the learning of all the finer details of song is postponed by the wild bird, just as by the experimental birds, until the advent of the critical period during the following spring. This is the time when the young chaffinch in the wild is first singing in a territory in competition with neighboring birds of the same species, and we have good evidence that wild birds learn the finer details of the song from their immediate neighbors. There is little doubt that it is primarily in this way that local song dialects, which so many field naturalists have noted, are built up and maintained. The young chaffinch thus learns the details of its full song by listening to older, experienced chaffinches. How it is that it does not also imitate and acquire the songs of other species we do not yet know for certain—probably by restricting its imitative attention to models of the right tonal quality. With the more generally imitative species there is evidence for what one must at present describe as imitation for its own sake. A chaffinch may presumably gain some advantage in its competition for maintenance of territories by being able quickly to modify its song so as to resemble that typical of the locality, but many species more proficient as songsters, and more generally imitative, seem to effect what can only be described as elegant improvisation, and the biological function of this and of the more extreme forms of vocal imitation is very difficult to assess. It seems that true vocal imitation must be regarded as a late development from inherited song patterns and must be looked on as characteristic of the most highly evolved among the true songbirds. It is hard to find any selective reason for the extreme purity and elaboration of some bird notes and songs. Releaser function appears in many cases to have been transcended. This feature has suggested to several authors that, in the finer details of songs, we see the beginnings of true artistic creation, and there is certainly no justification for ruling out such a hypothesis as fantastic or absurd. But perhaps tonal purity, inventiveness, and imitative ability are all examples of "preadaptation" for apparently remote and unlikely contingencies, specialization coming in advance of immediate adaptive requirements.

If this is true, such vocal performances are on a par with the number-sense which can be developed in many species of birds by careful training. The brilliant and painstaking work of Otto Koehler and his associates on the recognition of number by birds is one of the most remarkable developments in recent years in the study of animals' learning ability. Pitfalls in such experiments are numerous and extremely difficult to avoid, and only by the most careful experimental design and extreme pertinacity can the danger of "Clever Hans" errors be avoided. To do this was an experimental achievement of the highest class, and as a result we now know that some birds can "count" up to seven. Such counting ability seems to offer even less practical advantage for a wild bird than the features of song improvisation and imitation. Both are as yet set about with much mystery.

When we look at achievements such as the learning of elaborate songs and the other examples of animal behavior we have just been considering, we realize that the distinction between appetitive behavior and consummatory act has indeed become very tenuous. This is further illustrated by experiments on the following-response of young birds such as moorhens and coots. Here the very act of following a model, or the parent, has been shown (*15*) to be both appetitive and consummatory. This following, which is the active maintenance of a certain spatial relation to a chosen object, turns out to be its own reward; in other words, it is the maintenance of this spatial relationship which is the reinforcement. Similarly with the imitative birds, the very act of imitating, the very fact of achieving the appetitive behavior, seems itself to be the consummatory act.

Insight and Insight-Learning

In the foregoing examples of recent studies of animal behavior, we see, then, numerous instances of more or less elaborate, inborn releasive mechanisms guiding and restricting learning. We see inborn mechanisms developed by learning processes into perceptual and behavioral complexes of extraordinary elaboration, and we find, in insects and birds, instance after instance of the ability to perceive not simple sense data but relations between perceptions both simple and complex. These faculties are in fact what have—since the coming

of the Gestalt school—become known as insight and insight learning. There is still, of course, plenty of room for trial-and-error; these newer results do little to diminish its importance in the story. But completely unreflective trial-and-error—what Lloyd Morgan would have called *perceptive* trial-and-error—only, with no fore-plan or insight entering into the picture at all, is probably insufficient to account for behavior in animals where there is any evidence of elaborate perceptual organization. It seems to me inescapable that much modern work on animal behavior implies that the vast majority of metazoan animals are perceptive. Moreover, in all highly organized perceptions, the perception of relations involved implies something more. This, Lloyd Morgan would have taken to be self-consciousness. For Lloyd Morgan, the perceptive mind is conscious, but only the reflective type of mind is self-conscious—a distinction which sounds somewhat dated to our ears but which is nevertheless worth remembering. Insight learning can be defined, in Lloyd Morgan's phraseology, as action as a result of insight, by reflective organization, giving a new adaptive response, and a great deal of the modern evidence for insight-learning, imitation, play, number sense, and reminiscence gives reasons for considering animals to be reflective in his sense. Present-day students of animal behavior tend, not without reason, to avoid the word *consciousness,* and to perform displacement actions indicative of extreme anxiety whenever it is used with reference to animals. And we must indeed remember that perhaps Freud's most enduring claim to fame was his demonstration of the existence of highly elaborate mental processes far below the normally conscious level (*16*). Yet we are justified in using consciousness as a provisional biological hypothesis whenever we find directive behavior of such complexity that it cannot be fully or reasonably explained by mechanisms known to be operating within the body of the animal. Of course, if we can point to an efficient mechanism, that does not mean that true conscious-purpose is necessarily absent, even though, as practicing scientists, we may decide that, for the time being at any rate, it is no longer our concern.

I think, further, that the modern developments in the study of the higher-learning faculties of animals have served to emphasize the necessity for getting back to the idea of a carefully thought out combination of objective and subjective approach exemplified by Lloyd Morgan. The best instruments can be misused, and it is possible to cut our throats with Occam's razor and to disintegrate our animals with a blast from Lloyd Morgan's canon. If we try too rigidly to be objective, we may fail to see many important features of animal behavior which become clear to us when we attempt to put ourselves in the animal's place. While, of course, to go to the other extreme and be too subjective in approach is fatal—we must safeguard ourselves all the time with all the knowledge we have of the animal's sensory and behavioral capabilities. But I am convinced that a proper balance of the subjective and the objective is necessary both for a worthy ethology and a worthy psychology. Pure objectivity on the part of an external observer is in any case hardly feasible and, if achieved, will result in the neglect of much that is important. Perhaps it is excusable here to paraphrase and adapt some remarks of Lorenz (*17*) without, I hope, changing their essential meaning: "The true ethologist must be motivated not merely by a conscious effort to gain knowledge; for unless his eyes are bound to the object of his studies by that spellbound gaze, that sympathy which is evidenced by the mysterious charm that the beauty of living creatures works on some of us, he would be physically incapable of bringing himself to stare with sufficient persistence at fish, birds or mammals as is necessary to take stock of the behavior patterns of a species." If ethologists are right, then, that the guarded subjective approach (implying, as it does, something of the viewpoint of the artist) is one essential method in acquiring knowledge of animal nature, I believe it will ultimately be found that we have here a most important argument in support of those who conclude, as for instance does Erroll Harris (*18*) (from a vast knowledge of scientific advance and scientific philosophy), that empiricism, however necessary as a scientific technique, cannot possibly—from the nature of the case—supply an adequate scientific philosophy. But for a biologist this is treading on dangerous ground and I leave it hastily!

Essential Unity of Living Things

Finally we may ask, does this recent work on instinctive behavior and the percipient learning abilities of animals give us any fresh view of animal nature? The answer is, I think, undoubtedly that some apparent lines of demarcation between man and animal nature have become blurred. The fact just referred to, that so many animals in certain situations give evidences of being "reflective," in Lloyd Morgan's sense, and that, in so many cases, exploratory behavior, the mere getting to know an environment, is itself adequate reward, at once suggests resemblances with man. Many higher animals resemble man in their tendency to achieve consummatory situations rather than consummatory acts. The occurrence of displacement actions

in many animals when under the influence of conflicting instinctive drives shows remarkable superficial similarity to the effects of the conflict of learned or acquired drives (habits) in man. Animals suffering from "conflict" recall neurotic human beings in the same state to a degree that is often quite startling. Behavior study seems then to be reinforcing physiology in stressing the basic unity of the living system in more and more of its manifestations. Some of the fundamental thought processes of animals seem far less dissimilar from ours than we once thought, and we now see that even the bees have a propositional language, as distinct from the mere emotive influence which is the sole result of the language of so many animals—though of course there is no justification for assuming that the bees' communication is consciously intentional as is that of true human language. Propositional language was, until recently, thought to be the prerogative of human beings, and human language still seems to be unique in that it implies learning to use, as symbols, sounds or actions which in themselves have nothing of the *quality* of the objects which they denote (for example, number symbols).

But we may ask, further, does the modern study of animal behavior reinforce or run counter to the general trend of progress in other branches of biology? In the first place, I think it true to say that it is the conclusion of many and various disciplines that the world of living things appears now as far more of a unity than was conceivable 100 years ago. The post-Darwinian era in research has tended, on the whole, to break down barriers alike between phyla and between individual disciplines, and the same fundamental general principles are seen to be operating fairly widely through the animal and plant kingdom. Even the bacteria and the viruses, for all their strangeness, seem less remote than they once did. Apart from his famous canon, Lloyd Morgan's real claim to immortality is his development of the idea of emergent evolution and the contribution his thinking made to the concept of holism. Moreover, he wrote at a time when the boundary line between living and nonliving seemed as well defined as the English Channel. But how different it now is; a subtle change has manifested itself. It is not that analysis into ever finer levels of structure and physiology is showing progressively that biology is, after all, only the complicated physics and chemistry of an earlier generation. Far from it! To quote L. E. R. Picken (*19*): "The hope that analysis to ever finer levels of structure will ultimately reveal the nature of that relation by virtue of which the whole is more than the sum of the parts, has now been shown to be in vain. Most experimental biologists have, in the past, worked on the tacit or explicit belief that analysis in the terms of the physics and chemistry of fifty years ago—the physics of matter *en masse*, the chemistry of small molecules—would yield the answer. But we can see now that the physics and chemistry are going to be those of ordered aggregates far larger than molecules. The extent to which the concepts of chemistry and of physical chemistry have been modified sometimes almost out of existence—as in the case of the concept of the molecule—by contact with biological material is of the greatest historical importance." Increasingly, biological organization now seems apparent in circumstances and conditions where, not so long ago, all was thought to be physics and chemistry, and it seems not improbable that future advance may come by starting with concepts derived from the biological sciences and working back into the physical sciences. In fact the present position of biological philosophy is one which Lloyd Morgan foresaw, and some of his statements can be lifted right out of their former contexts and used in present-day writing without seeming in the least out of date.

Ethology has as yet little, itself, to say on this fundamental issue of living and nonliving, but it does make an impressive contribution to the chorus of voices which are emphasizing the essential unity of living things and the similarity, in much that is fundamental, between animals and man. But while this is true it would be a view of the utmost naïveté to assume that studies of animal behavior imply any decrease in the stature of man. For it is sound scientific common sense to see that, if only because of the existence of science itself, man displays emergent qualities far transcending those of the organisms most nearly related to him. Moreover, his high powers of abstract reasoning, his faith, the depths of his spiritual life, his appreciation of moral values, his self-conscious discipline of the will to achieve abstract values, not only differentiate him from the animals; these and all the other manifestations which have already emerged suggest that he possesses vast further potentialities yet to be realized in both individual and evolutionary development.

References and Notes

1. C. Sherrington, *The Integrative Action of the Nervous System* (New York, 1906).
2. C. L. Morgan, *Introduction to Comparative Psychology* (London, 1894).
3. J. H. Woodger, *Biological Principles: A Critical Study* (London, 1929).
4. W. E. Agar, *The Theory of the Living Organism* (Melbourne University Press, 1943).
5. K. Lorenz, *J. Ornithol.* **83**, 137, 289 (1935); *Zool. Anz. Supp.* **12**, 69 (1939).

6. K. S. Lashley, *Psychological Rev.* **45**, 445 (1938).
7. R. S. Woodworth, *Dynamic Psychology* (New York, 1918).
8. M. Lindauer, *Z. Vergleich. Physiol.* **34**, 299 (1952).
9. H. Gleitman, *J. Comp. and Physiol. Psychol.* **48**, 77 (1955). It is noteworthy that Gleitman has recently established that a rat can learn certain features of a spatial pattern without any experience of performance but merely as a result of being passively taken along the path.
10. W. E. Agar, *Philos. Sci.* **15**, 179 (1948). Agar argues that purposeful behavior in human beings is a development of a property of all living organisms, as fundamental to them as assimilation and growth.
11. M. Lindauer, *Naturwissenschaften* **38**, 509 (1951); *Z. Vergleich. Physiol.* **37**, 263 (1955).
12. G. V. T. Matthews, *Bird Navigation* (Cambridge, 1955).
13. P. Sauer and E. Sauer, *Rev. suisse zool.* **62**, 250 (1955).
14. W. H. Thorpe, *Nature* **173**, 465 (1954); *Learning and Instinct in Animals* (London, 1956).
15. R. A. Hinde, W. H. Thorpe, M. A. Vince, *Behavior* **9**, 214 (1956).
16. Freud was so lacking in the comparative approach that, except insofar as he emphasized the reality of specifically partitioned internal drive, his theorizing on instinct is virtually useless to the student of animal behavior. It seems likely that, in time, Jung's thought, particularly as it bears on problems of the innate releasive mechanism, will be found to contain much more of value to the ethologist.
17. K. Lorenz, *Symposia Soc. Exptl. Biol.* **4** (1950).
18. E. E. Harris, *Nature, Mind and Modern Science* (London, 1954).
19. L. E. R. Picken, *School Sci. Rev.* **36**, 262, 332 (1955).

BOOK REVIEWS

World Symposium on Applied Solar Energy, Proceedings. Sponsored by the Association for Applied Solar Energy, Stanford Research Institute, Calif., and the University of Arizona, 1–5 Nov. 1955. Association for Applied Solar Energy, Phoenix, Ariz., 1956. 304 pp. $5.

The opening of a new chapter in any field of science and engineering should always be marked with proper solemnity. Bright Arizona sunshine greeted nearly 1000 scientists, engineers, and members of industry at the symposium that raised the curtain on "The uses of solar energy," held in Tucson and Phoenix, in November 1955. The proceedings of the World Symposium on Applied Solar Energy have appeared in a very handsome, large volume of some 300 pages, which summarizes the lectures presented by distinguished scientists. Excellent photographs and drawings illustrate the meetings, exhibits, and articles.

Although the book is a collection of papers and not a textbook, the editors have attempted to harmonize the articles and to avoid duplication. This is a *must* book for all who are interested in this new field of tremendous possibilities in the attempt to bring the sun "within our reach."

Past accomplishments were carefully surveyed by Farrington Daniels (University of Wisconsin). Mechanical aspects and the history of solar engines were stimulatingly reviewed by R. C. Jordan (University of Minnesota).

Felix Trombe (research director of the National Center of Scientific Research, France) presented the latest results of his large solar furnaces, built at the Solar Energy Laboratory at Montlouis, France. The possibility of reaching ultrahigh temperatures at a reasonable ultimate cost appears to be assured.

Solar house heating and cooling received special attention and was treated during a panel discussion. The panel consisted of Harold Heywood (Imperial College of Science and Technology, University of London), Austin Whillier (Council for Scientific and Industrial Research, Pretoria, South Africa), George O. G. Löf (Denver, Colorado), Maria Telkes (College of Engineering, New York University), and Raymond W. Bliss, Jr. (Donovan & Bliss, Amado, Arizona). Although only a few solar-heated test houses have been built thus far, extensive calculations have been made for practically any location and climatic condition. The collection and storage of solar energy appear to be the key problems. Solar house heating was considered, even by pessimists, to be "on the border of feasibility." Improvements in design of the collectors, to decrease their cost by about one-half, may create the necessary "break-through" in this field. Selective absorbing coatings can decrease heat losses from solar collectors. Numerous other potential improvements have been discussed. Different methods for the accumulation or storage of solar energy as heat could, with further efforts, be economically applied.

The subject of solar water heaters was reviewed by R. N. Morse (Commonwealth Scientific and Industrial Research Organization, Australia).

The problem of solar cooling, the proposed "self-energizing" method of bringing comfort to the tropics, was attacked, with emphasis on the use of heat pumps and solar versions of existing cooling systems.

Solar stills may be developed to convert sea water or other salty water into fresh drinking water

on a large scale, at a reasonably economical level, even to the point where "previously arid regions will be supplied by rivers of fresh water flowing backward from the oceans."

The possibility of culturing algae was reviewed by Jack Myers (University of Texas). Large-scale test results and cost analysis were presented by Hiroshi Tamiya of Japan. Austin W. Fisher, Jr. (Arthur D. Little) indicated that this method is still too expensive for practical use. Possible improvements in the growth of plants may yield unexpected results, according to Kenneth V. Thimann (Harvard University).

Generation of electricity from the sun by means of solar batteries is already technically feasible, according to G. L. Pearson (Bell Telephone Laboratories). The tremendous possibilities of solar power as envisioned abroad were summarized by V. A. Baum (Heliotechnical Laboratory, Moscow).

The world symposium and its proceedings were undoubtedly a great success. The book has been out of print for some months, but the second printing may soon be available for those who want to take a closer look at the tremendous possibilities of "reaching the sun."

MARIA TELKES

New York University

Aspects of Culture. Harry L. Shapiro, Rutgers University Press, New Brunswick, N.J., 1956. 147 pp. $2.75.

The 1956 Brown and Haley lectures at the College of Puget Sound, Tacoma, Washington, were delivered by Harry L. Shapiro and provide the contents of this little volume. In the foreword the author says that his purpose is to direct attention to the manner in which a better understanding of our daily lives, of current international problems, of history, and of civilization is made possible by the modern discovery of culture. Proceeding on the premise that culture has made us what we are and will determine what we are to be, he discusses three major topics, (i) the discovery of culture, (ii) culture and history, and (iii) the light that recovery of the past throws on the growth and concepts of culture.

Despite limitations of time and space, Shapiro highlights a surprising variety of subjects and presents many stimulating ideas, some of which may prove to be controversial. He reviews the long course of vertebrate evolution leading up to man and to the conclusions that culture was made inevitable by the process and that the effect of culture on human evolution constitutes a continuation of evolution itself. With reference to culture and history, several examples are given to show how anthropologic knowledge can bring to history a broader and deeper understanding of past events and a better explanation of their significance than is provided by the usual narrative approach. An outline of the origin, cycles, continuity, and patterns of civilization links the past to the present and serves to round out Shapiro's concept of culture. The book is thought-provoking and well worth reading.

FRANK H. H. ROBERTS, JR.

Smithsonian Institution

The Great Chain of Life. Joseph W. Krutch. Houghton Mifflin, Boston, 1957. 227 pp. Illus. $3.75.

Every inquisitive and introspective man has, at one time or another, asked himself the questions: "Who am I?" "What am I?" The author of *The Great Chain of Life,* a gifted, introspective naturalist, wrestles with these fundamental questions and admits that probably man is part god, part animal, and part machine, with the second element in the largest proportion.

The story begins with an examination of the theories and evidence of the origin of life, and we learn that the apparently simple microscopic and semimicroscopic organisms are exceedingly complex. The discussion of the morphology, physiology, and behavior of *Volvox* is an introduction to "the machinery for evolution." A unique, nontheological discussion of the doctrine of "original sin" is developed from a discussion of the animal's first need—food. Man at first, like the lower animals, did not make a living but found one. Now he alone has made of eating an art and a ritual. Even in the making of that living, man has painstakingly learned techniques of agriculture and food preparation and processings that lower animals carry on instinctively as part of their organized, specialized, community life.

The story of parenthood, with love and without love, raises important questions about the extent to which animals live in an emotional world, as man does. Then, the mysteries of morphology, transformation, growth, and the continuity of all forms of life through an immortal germ plasm are portrayed.

Comparative discussions of the gregariousness and social organization of animals, the degrees of awareness manifested by various animal groups, and the undeveloped potentialities of different spe-

cies provide new insights into the evolutionary history of life. We see that, at times, the evolutionary process has reversed itself. Finally, the author brings the evidence of his entire discussion and the opinions of other scholars and disciplines to bear on the question: "How right was Darwin?"

The "Epilogue" is a series of musings on some of the other mysteries of life and living creatures. These are certain to stimulate the thought processes of the reader into still other avenues of speculation about what he is.

The audience for this book is everybody. Its great appeal lies in the mysteries unfolded from familiar subject matter and the revelation of the significance to man of habits and instincts we so often have observed and considered to be important only to the species exhibiting them.

HILARY J. DEASON
Science Library Program, AAAS

An Encyclopaedia of the Iron and Steel Industry. Compiled by A. K. Osborne. Philosophical Library, New York, 1956. 558 pp. Illus. $25.

This encyclopedia provides a concise description of the materials, plant, tools, and processes used in the iron and steel industry, and in related industries, from the preparation of the ore to the finished product, and it defines the technical terms employed in the industry. Appendix V gives a useful list of names and addresses of scientific, technical, and trade societies and other bodies related to the industry.

A. K. Osborne is technical librarian and information officer of the Brown-Firth Research Laboratories, Sheffield, England.

The Galathea Deep Sea Expedition 1950–1952. Described by members of the expedition. Anton F. Bruun, Sv. Greve, Hakon Mielche, and Ragnar Sparck. Translated from the Danish by Reginald Spink. Macmillan, New York, 1956. 296 pp. Illus. $8.

There are several thousand biologists in America, but few of them have been aboard a seagoing research vessel. The exciting minutes when a deep-sea net is hauled in and all hands gather around to see the catch are hard to describe. I have witnessed this several times, though only off Bermuda and with hauls from depths of about 1000 meters. Anton Bruun and the other members of the Galathea expedition not only have fully captured these exciting moments but have also written an excellent and varied report of their complex research assignments.

The first and foremost of these was, to quote: "to explore the ocean trenches in order to find out whether life occurred under the extreme conditions prevailing there—and if so, to what extent. Our second object was to seek more information, by making greater use of large-scale dredging implements than had been done in the past, as to whether, and to what extent, there are large and active animals in the abyss, also at somewhat higher levels. Thirdly, we wished to study the bottom fauna; that is to say, to gauge the amount of living animals per square metre of sea-bed, by a method first employed in Danish waters. It seemed a natural task for a Danish expedition to extend this method to the unknown deep and the unfamiliar coastal waters in the tropical regions which we proposed to visit, and which had never been explored by such methods."

There were other objectives, such as investigations of productivity in various parts of the world's ocean (Steman-Nielsen), geomagnetic research in abyssal regions (Niels Arley), and various faunistic and ethnologic studies in the Pacific area.

The Galathea is a 1600-ton former naval sloop, reconditioned and fitted out as an oceanic research vessel, with the benefit of much previous Danish experience in marine research. She was on her voyage from 1950 to 1952. Her scientific staff was predominantly Danish but included personnel from several other nations. The number of scientists varied from 16 to 38 during these 2 years, and it was only to be expected that their activities would run the gamut of many fields of biology. The book describes most of them, and it is therefore almost kaleidoscopically varied.

I shall restrict myself, here, to mention of only the very meat of the report—the bottom trawling in the deep ocean trenches. These hauls in the Philippines, Kermadec, Banda, and Sunda trenches have, as Bruun says, "extended the downward limits of our knowledge." This is a restrained statement, for 28 groups of invertebrates and some fishes were taken by the Galathea from regions far deeper than those in which they had previously been known to occur.

The description of sea cucumbers, bivalves, and crustaceans, from depths of 10,000 meters, would be interesting in itself, but in addition to pictures of these bizarre forms we are given many facts about their adaptations to extreme depths. One sea cucumber, *Elpidia glacialis,* was found in three different trenches that were separated from one another by much shallower regions; it may even belong to the same species as some very similar

animals taken, almost at the surface, in the Arctic. Does this imply tolerance of widely varying pressures? (The temperature in the deep trenches and in the Arctic would, of course, be comparable.) This explanation for the wide distribution of the animals is suggested, but it will take other concentrated efforts of team research like that of the Galathea before we can do more than speculate about the many questions raised in the book.

In the meantime, Bruun, his colleagues, and his publishers should be congratulated for giving us, so soon after the return of the Galathea, such a captivating first account of their accomplishments.

JOHN E. BARDACH

University of Michigan

Discussions on Child Development. A consideration of the biological, psychological, and cultural approaches to the understanding of human development and behavior. *Proceedings of the World Health Organization Study Group on the Psychobiological Development of the Child:* vol. I, first meeting, Geneva, 1953; vol. II, second meeting, London, 1954. J. M. Tanner and Bärbel Inhelder, Eds. International Universities Press, New York, 1957. 240 pp.; 271 pp. Illus. $10 per set.

Conferences come and conferences go. Some leave behind, in permanent form, the papers and discussions for those who could not be present. Fortunately, because of the demand for the mimeographed copies, the proceedings of the first and second meetings of the World Health Organization Study Group on the Psychobiological Development of the Child have been printed. The result not only gives a compact report on current scientific research and controversy in child development and related behavior fields but also reveals a good model of the way in which distinguished scientists from various disciplines and countries can work together in a conference setting. No review can do justice to the range and variety of the research areas covered by the presentations by the various scientists of their own work and to the discussions, among the conferees and guests, that followed. Some of the most stimulating work on human and animal behavior done in recent years, or now going on, appears in these volumes. The discussion is animated and is seldom irrelevant, even though it sometimes moves away from the human child into the problems of other developmental levels and of the young of other species.

In volume I, J. M. Tanner, a biologist, presents the physical and physiological aspects of child development; Marcel Monnier, an electrophysiologist, the behavior of newborn anencephalics with various degrees of anencephaly; Bärbel Inhelder, a psychologist, the criteria of the stages of mental development, based on Jean Piaget's work; Konrad Lorenz, an ethologist, comparative behaviorology (a discussion of imprinting); Grey Walter, an electrophysiologist, the electroencephalographic development of children; René Zazzo, a psychologist, the stages of psychological development of the child; John Bowlby, a psychoanalyst, psychoanalytic instinct theory; and Margaret Mead, an anthropologist, the cross-cultural approach to child development problems.

In volume II, Grey Walter describes electronic-mechanical models built by him to illustrate various aspects of learning and behavior; Dalbir Bindra, a psychologist, describes the work of Hebb's laboratory at McGill University on the isolation of dogs from stimulation, on sensory deprivation in human beings, and on stress; Howard Liddell, a psychobiologist, presents his work on experimentally produced neuroses in sheep and goats and his deprivation and shock studies; John Whiting, an anthropologist, discusses cross-cultural studies of child training in the light of learning theory; Bowlby shows a film and discusses a child's response in a separation situation; and Lorenz shows a film and discusses the behavior of human prematures, newborns, and infants from birth to 1 year of age.

The volumes are well edited. They preserve the flavor of the original discussion and have (something few conference proceedings have) a good index. I found the books stimulating; in fact, once I had started, I could hardly stop reading.

JOHN E. ANDERSON

University of Minnesota

Advances in Electronics and Electron Physics. vol. VIII. L. Marton, Ed. Academic Press, New York, 1956. 562 pp. Illus. $13.

The editor of this volume draws attention in his preface to the fact that more scientists and engineers are now willing to review their field of interest and research. This is the more gratifying as the volume of published (and, alas, also of unpublished) research is increasing at an alarming rate, and it is impossible to get an adequate, up-to-date impression of what is going on in fields of physics outside one's own limited range of research. Fortunately, the situation has not yet deteriorated as far as in mathematics, where experts in different branches can hardly understand each other's cur-

rent research, and the publication, in increasing numbers, of survey volumes such as the present one gives physicists the possibility, at least, of learning about other subjects, or of finding out, without having to go back to the original, widespread literature, what has been done in other fields.

The present volume is largely devoted to electronics and should, therefore, be of particular interest to experimental physicists, practically all of whom, nowadays, use electronic devices of one kind or another. As a very minor point of criticism one might, perhaps, point to the fact that all articles are strongly experimental in flavor and, possibly as a result of this, do not contain as many hints and suggestions for possible future research, either experimental or theoretical, as was the case in earlier volumes in this series. The article by Metson is the only one with such a section, called "Review of some outstanding problems."

The volume begins with an article by King and Zacharias on "Some new applications and techniques of molecular beams." After that, there are articles by Dyke and Dolan ("Field emission"), Kerwin ("Mass spectroscopy"), Baldinger and Franzen ("Amplitude and time measurement in nuclear physics"), Churchill and Curran ("Pulse amplitude analysis"), Süsskind ("Electron guns and focusing for high-density electron beams"), Metson ("On the electrical life of an oxide-cathode receiving tube"), Knoll and Kazan ("Viewing storage tubes"), and Okress ("Magnetron mode transitions"). All articles end with extensive bibliographies. Those for the articles by King and Zacharias, by Kerwin, and by Okress are extremely long and seem to me to be as comprehensive as one can expect. There is also an author index and an adequate subject index to the volume.

D. ter Haar

Oxford University, England

The Wind and the Weather. Joe Bolton. Crowell, New York, 1957. 277 pp. $3.95.

The Wind and the Weather, a reorganization of the scripts of a series of television programs, contains much that is of particular interest, such as records of heavy snowfalls, rainfalls, large hailstones, gales, and low and high temperatures. Famous epidemics are discussed, on the assumption that they occur in cycles or that they correlate with the weather. The development of weather forecasting receives considerable attention. Sources of the information are not given, although a few individuals are mentioned. The scientific errors are relatively few.

This book will stimulate the interest of those who are intrigued by the weather. It presents, vividly, numerous spectacular aspects of the weather, discusses our increasing knowledge about it, and includes some recent developments.

Stephen S. Visher

Indiana University

Books Reviewed in Science

5 April

Physical Methods in Chemical Analysis, vol. III, W. G. Berl (Academic). Reviewed by I. M. Kolthoff.

Principles of Zoology, J. A. Moore (Oxford Univ. Press). Reviewed by J. T. Velardo.

Physics, J. S. Marshall and E. R. Pounder (Macmillan). Reviewed by W. M. MacDonald.

12 April

Some Protozoan Diseases of Man and Animals: Anaplasmosis, Babesiosis, and Toxoplasmosis, Annals of the New York Academy of Science, vol. 64, art. 2 (New York Acad. of Science). Reviewed by R. L. Farrell.

Handbuch der Physik, vol. XV, *Low Temperature Physics II*, S. Flügge, Ed. (Springer). Reviewed by R. P. Hudson.

Youth in a Soundless World, E. S. Levine (New York Univ. Press). Reviewed by S. A. Kirk.

Amino Acid Handbook, R. J. Block and K. W. Weiss (Thomas).

Archimedes, vol. 12, *Acta Historica Scientiarum Naturalium*, E. J. Dijksterhuis (Munksgaard). Reviewed by I. E. Drabkin.

They've Got Your Number, R. Wernick (Norton). Reviewed by M. J. Rosenberg.

26 April

Science in the Federal Government, A. H. Dupree (Belknap Press of Harvard Univ.). Reviewed by D. Wolfle.

The 1955 University of Utah Research Conference on the Identification of Creative Scientific Talent, C. W. Taylor, principal investigator (Univ. of Utah Press). Reviewed by R. M. W. Travers.

Biographical Memoirs of the Fellows of the Royal Society, vol. 2 (Royal Society). Reviewed by G. DuShane.

Dahlak, G. Roghi and F. Baschieri; translated by P. Hastings; E. Brockett, Ed. (Essential Books). Reviewed by W. Beebe.

American Men of Science, vol. III, *The Social and Behavioral Sciences*, J. Cattell, Ed. (Bowker). Reviewed by L. Carmichael.

British Scientific and Technical Books (Clarke, Hafner).

UNESCO Source Book for Science Teaching (United Nations Educational, Scientific, and Cultural Organization). Reviewed by G. DuShane.

A World Geography of Forest Resources, S. Haden-Guest, J. K. Wright, E. M. Teclaff, Eds. (Ronald). Reviewed by H. I. Winer.

Theoretical Genetics, R. B. Goldschmidt (Univ. of California Press). Reviewed by E. Caspari.

The Dentition of the Australopithecinae, J. T. Robinson (Transvaal Museum). Reviewed by G. G. Simpson.

Animal Navigation, J. D. Carthy (Scribner). Reviewed by A. Novick.

The Open Sea, A. C. Hardy (Houghton Mifflin). Reviewed by J. W. Hedgpeth.

Rauwolfia: Botany, Pharmacognosy, Chemistry and Pharmacology, R. E. Woodson, Jr., H. W. Youngken, E. Schlittler, J. A. Schneider (Little, Brown). Reviewed by W. Cutting.

Pharmacognosy, E. N. Gathercoal and E. H. Wirth; rev. by E. P. Claus (Lea and Febiger). Reviewed by F. T. Maher.

An Atlas of Diseases of the Eye, E. S. Perkins and P. Hansell (Little, Brown). Reviewed by R. L. Pfeiffer.

Textbook of Human Anatomy, J. D. Boyd, W. E. LeGros Clark, W. J. Hamilton, J. M. Yoffey, S. Zuckerman, A. B. Appleton (Macmillan, London). Reviewed by W. T. Dempster.

Lehrbuch der Tropenkrankheiten, E. G. Nauck (Thieme). Reviewed by E. C. Faust.

Pica, M. Cooper (Thomas). Reviewed by C. D. Leake.

Edward Palmer, Plant Explorer of the American West, R. McVaugh (Univ. of Oklahoma Press). Reviewed by E. Anderson.

Philosophy of Science, G. Bergmann (Univ. of Wisconsin Press). Reviewed by I. Scheffler.

A History of Technology, vol. II, *The Mediterranean Civilizations and the Middle Ages*, C. Singer *et al.* (Clarendon). Reviewed by W. D. Stahlman.

History of Analytical Geometry, C. B. Boyer (Scripta Mathematica, Yeshiva Univ.). Reviewed by A. Rosenthal.

Pion Physics, vol. 2 of *CERN Symposium on High Energy Accelerators and Pion Physics, Proceedings* (European Organization for Nuclear Research). Reviewed by E. Creutz.

Handbuch der Physik, vol. XXI, *Gas Discharges I*; vol. XXII, *Gas Discharges II*, S. Flügge, Ed. (Springer). Reviewed by L. B. Loeb.

Solid State Physics, vol. III, F. Seitz and D. Turnbull, Eds. (Academic). Reviewed by A. F. Kip.

The Encyclopedia of Chemistry, G. L. Clark, Ed. (Reinhold).

Advances in Chemical Engineering, T. B. Drew and J. W. Hoopes, Jr. (Academic). Reviewed by R. Morgen.

Engineering Structural Failures, R. Hammond (Philosophical Library). Reviewed by J. Feld.

Elements of Partial Differential Equations, I. N. Sneddon (McGraw-Hill). Reviewed by M. Golomb.

The Sun. G. Abetti (Macmillan). Reviewed by F. K. Edmondson.

Arizona's Meteorite Crater, H. H. Nininger (American Meteorite Museum). Reviewed by J. S. Rinehart.

Dynamic Meteorology and Weather Forecasting, C. L. Godske, T. Bergeron, J. Bjerknes, R. C. Bundgaard (American Meteorological Society and Carnegie Institution). Reviewed by S. Petterssen.

The Structure of a Moral Code, J. Ladd (Harvard Univ. Press). Reviewed by A. C. Danto.

The Foundations of Science and the Concepts of Psychology and Psychoanalysis, vol. I of *Minnesota Studies in the Philosophy of Science*, H. Feigl and M. Scriven, Eds. (Univ. of Minnesota Press). Reviewed by H. H. Kendler.

Perspectives in Personality Theory, H. P. David and H. von Bracken (Basic Books). Reviewed by C. McArthur.

Theories of Personality, C. S. Hall and G. Lindzey (Wiley). Reviewed by A. L. Baldwin.

Archaeology and Its Problems, S. J. De Laet; translated by R. Daniel (Macmillan). Reviewed by F. de Laguna.

Bones for the Archaeologist, I. W. Cornwall (Macmillan). Reviewed by L. Eiseley.

Meeting Prehistoric Man, G. H. R. von Koenigswald; translated by M. Bullock (Harper). Reviewed by L. Eiseley.

New Books

Experimental Psychology and Other Essays. I. P. Pavlov. Philosophical Library, New York, 1957. 653 pp. $7.50.

Osteology of the Reptiles. Alfred S. Romer. University of Chicago Press, Chicago, 1957. 722 pp. $20.

Atoms for the World. United States participation in the Conference on the Peaceful Uses of Atomic Energy. Laura Fermi. University of Chicago Press, Chicago, 1957. 227 pp. $3.75.

In-Service Education for Teachers, Supervisors, and Administrators. Fifty-sixth yearbook, pt. 1. Nelson B. Henry, Ed. National Society for the Study of Education, 1957. Distributed by University of Chicago Press, Chicago, Ill. 376 pp. Paper, $3.25; cloth, $4.

The Road to Inner Freedom. Baruch Spinoza. Introduction by Dagobert D. Runes, Ed. Philosophical Library, New York, 1957. 215 pp. $3.

General Geography for Colleges. O. D. Von Engeln and Bruce C. Netschert. Harper, New York, 1957. 681 pp. $7.50.

Dairy Microbiology. Edwin M. Foster, F. Eugene Nelson, Marvin L. Speck, Raymond N. Doetsch, Joseph C. Olson, Jr. Prentice-Hall, Englewood Cliffs, N.J., 1957. 492 pp. $5.65.

Flotation. A. M. Gaudin. McGraw-Hill, New York, ed. 2, 1957. 573 pp. $12.50.

Hormones, Brain Function, and Behavior. Proceedings of a Conference on Neuroendocrinology held at Arden House, Harriman, New York, 1956. Hudson Hoagland, Ed. Academic Press, New York, 1957. 257 pp. $7.

German Influence upon English Education and Science, 1800–1866. Monograph No. 6. George Haines, IV. Connecticut College, New London, 1957. 106 pp. $3.50.

Neoplasms of the Domesticated Mammals, a Review. Review Series No. 4 of the Commonwealth Bureau of Animal Health. E. Cotchin. Commonwealth Agricultural Bureaux, Farnham Royal, Bucks, England, 1956. 100 pp.

(*Continued on page vi*)

Index to Volume 84 (January–June 1957)

[Note: In all divisions of this index, the letter (L) following a title indicates a letter to the editors.]

Title Index of Articles and Letters

AAAS affairs: AAAS council meeting, 1956, D. Wolfle, 151; AAAS membership, 204; AAAS officers, committees, and representatives for 1957, 201; AAAS Pacific division meets, R. C. Miller, 53; AAAS socio-psychological prize, 264; Applications solicited for traveling library program, 212; Dedication of the new AAAS headquarters building, P. B. Sears, 24; New York meeting in retrospect, R. L. Taylor, 204; Preliminary report of AAAS Interim Committee on the Social Aspects of Science, W. Pigman, B. Commoner, G. Lasker, C. D. Leake, B. H. Williams, 146; Regional consultants on science and mathematics teaching, J. R. Mayor, 154; Tatum named to editorial board, G. DuShane, 264

Canalization of the Moselle, W. E. McIntyre, 255
Changing energy scene, C. A. Scarlott, 221
Colorado dam controversy (L), P. H. Shepard, Jr.; A. M. Woodbury, 199

Dedication of the new AAAS headquarters building, P. B. Sears, 24

Ecology and overpopulation, L. R. Dice, 165

Formation of the elements, W. A. Fowler, 84; erratum, 200

Genetics in animal breeding, I. M. Lerner, 183
Genetics counselors (L), A. Scheinfeld, 199
Global distribution of strontium-90 from nuclear detonations, M. Eisenbud, 237

International observatory, An, J. B. Irwin, 111

Jungle brimstone, W. Haynes, 128

Livestock parasites and grass, B. Schwartz and H. H. Vegors, 229

Man's place in living nature, H. J. Muller, 245
Meteorology in the International Geophysical Year, H. Wexler, 141

Nature of genius, E. Jones, 75
Nautical charting, A. L. Shalowitz, 290

Oil shale and bituminous sand, F. L. Hartley and C. S. Brinegar, 275

Political science of science, H. D. Lasswell, 34
Present crisis in science education (L), W. P. Betham, Jr., 197

Radiation and genetics, L. C. Dunn, 6
Radiation and the human body, S. Warren, 3
Rice culture in Spain, R. E. Crist, 66
Role of statistics in scientific research, J. W. Mayne, 26

Scientists through adolescent eyes: what we need to know, why we need to know it, D. N. Michael, 135
Silverfish, a paper-eating insect, R. Lasker, 123
Sinkholes, bottomless lakes, and the Pecos River, E. R. Harrington, 302
Solar energy on clear and cloudy days, S. Fritz, 55
Some implications of the study of animal behavior, W. H. Thorpe, 309
Studies on deep mass culture of algae in Israel, A. M. Mayer, A. Eisenberg, M. Evenari, erratum, 200

Thomas Henry Huxley, C. S. Blinderman, 171

Uses of atomic radiation and energy, L. R. Hafstad, 11

What we most need to know, L. H. Snyder, 17
What's wrong with phonics (L), N. N. Neal, 198
When is human behavior predetermined? E. G. Boring, 189

Author Index

Anderson, J. E., Book review, 323

Bardach, J. E., Book review, 322
Bates, G. E., Book review, 104
Beetham, W. P., Jr., Present crisis in science education (L), 197
Berry, E. W., Book review, 45, 106
Blinderman, C. S., Thomas Henry Huxley, 171
Boring, E. G., When is human behavior predetermined? 189
Boyd, W. C., Book review, 213
Brinegar, C. S. *See* Hartley, F. L., 275
Brownlee, K. A., Book review, 48
Burns, A. E., Book review, 216
Burr, H. S., Book review, 156
Byerly, T. C., Book review, 105

Carlander, K. D., Book review, 266
Commoner, B., Preliminary report of AAAS Interim Committee on the Social Aspects of Science, 146
Corson, S. A., Book review, 47
Crist, R. E., Rice culture in Spain, 66

Daggs, R. G., Book review, 324
DallaValle, J. M., Book review, 270
Deason, H. J., Book review, 321
Dice, L. R., Ecology and overpopulation, 165
Dukes, W. F., Book review, 49
Dunn, L. C., Radiation and genetics, 6
DuShane, G., Tatum named to editorial board, 264

Edmondson, F. K., Book review, 50
Eisenberg, A. *See* Mayer, A. M., 200
Eisenbud, M., Global distribution of strontium-90 from nuclear detonations, 237
Ewan, J., Book review, 161

Fleischer, R., Book review, 103, 214
Fowler, W. A., Formation of the elements, 84; erratum, 200
Fritz, S., Solar energy on clear and cloudy days, 55

Gardner, P. V., Book review, 267
Gardner, T. S., Book review, 44

Haar, D. ter, Book review, 323
Hafstad, L. R., Uses of atomic radiation and energy, 11
Hancock, J., Book review, 103, 160

Harrington, E. R., Sinkholes, bottomless lakes, and the Pecos River, 302
Hartley, E. L., Book review, 271
Hartley, F. L., and C. S. Brinegar, Oil shale and bituminous sand, 275
Haynes, W., Jungle brimstone, 128
Herzfeld, R. F., Book review, 216

Iltis, H. H., Book review, 266
Irwin, J. B., An international observatory, 111

Jones, E., Nature of genius, 75

Kaikow, J., Book review, 215
Knapp, R. H., Book review, 104

Lasker, G., Preliminary report of AAAS Interim Committee on the Social Aspects of Science, 146
Lasker, R., Silverfish, a paper-eating insect, 123
Lasswell, H. D., Political science of science, 34
Leake, C. D., Preliminary report of AAAS Interim Committee on the Social Aspects of Science, 146
Lerner, I. M., Genetics in animal breeding, 183

Mayer, A. M., A. Eisenberg, M. Evenari, Studies on deep mass culture of algae in Israel, erratum, 200
Mayne, J. W., Role of statistics in scientific research, 26
Mayor, J. R., Regional consultants on science and mathematics teaching, 154
McIntyre, W. E., Canalization of the Moselle, 255
Michael, D. N., Scientists through adolescent eyes: what we need to know, why we need to know it, 135
Miller, R. C., Pacific division meets, 53
Milne, L. J., Book review, 108
Milne, M. *See* L. J. Milne, 108
Muller, H. J., Man's place in living nature, 245
Multhauf, R. P., Book review, 102, 213, 269

Neal, N. N., What's wrong with phonics? (L), 198
Newell, H. E., Jr., Book review, 158

Pigman, W., Preliminiary report of AAAS Interim Committee on the Social Aspects of Science, 146

Richards, H. G., Book review, 161
Ristow, W. W., Book review, 159
Roberts, F. H. H., Jr., Book review, 321
Romer, A. S., Book review, 101
Rosenberg, M. J., Book review, 102

Scarlott, C. A., Changing energy scene, 221
Scheinfeld, A., Genetics counselors (L), 199
Schoggen, P. H., Book review, 269
Schwartz, B., and H. H. Vegors, Livestock parasites and grass, 229
Sears, P. B., Dedication of the new AAAS headquarters building, 24
Shalowitz, A. L., Nautical charting, 290
Shepard, P. H., Jr.; A. M. Woodbury, Colorado dam controversy (L), 199
Siegfried, R., Book review, 157
Singleton, W. R., Book review, 107
Smith, H. H., Book review, 46
Snyder, L. H., What we most need to know, 17
Staebler, U. M., Book review, 160
Syer, H. W., Book review, 217

Taylor, R. L., New York meeting in retrospect, 204
Telkes, M., Book review, 320
Thorpe, W. H., Some implications of the study of animal behavior, 309
Tyler, L. E., Book review, 48

Vegors, H. H. *See* Schwartz, B., 229
Velardo, J. T., Book review, 45
Visher, S. S., Book review, 324

Wallen, I. E., Book review, 44, 214, 270
Warren, S., Radiation and the human body, 3
Wexler, H., Meteorology in the International Geophysical Year, 141
Williams, B. H., Preliminary report of AAAS Interim Committee on the Social Aspects of Science, 146
Wolffe, D., AAAS council meeting, 1956, 151
Woodbury, A. M. *See* Shepard, P. H., Jr., 199

Young, J. H., Book review, 108

Zingg, A. W., Book review, 267

Books Reviewed

Advances in Electronics and Electron Physics, vol. VIII, L. Manton, Ed., 323
Ansbacher, H. L., and R. R. Ansbacher, Eds., *Individual Psychology of Alfred Adler*, 271
Ansbacher, R. R. *See* Ansbacher, H. L., 271
Aquatic Insects of California, with Keys to North American Genera and California Species, R. L. Usinger, Ed., 108
Aspects of Culture, H. L. Shapiro, 321

Between the Planets, F. G. Watson, 103
Biological Treatment of Sewage and Industrial Wastes, vol. 1, *Aerobic Oxidation*, J. McCabe and W. W. Eckenfelder, Jr., Eds., 214
Bolton, J., *The Wind and the Weather*, 324
Botanical Exploration of the Trans-Mississippi West, 1790–1850, S. D. McKelvey, 161
Braun, W. von. *See* Ley, W., 44
Brown, W. L. *See* Wallace, H. A., 107
Bruun, A. F., S. Greve, H. Mielche, R. Sparck, *The Galathea Deep Sea Expedition*, 322
Burkitt, M. C., *The Old Stone Age*, 216

Calder Hall, K. Jay, 160
Callaghan, A. R., and A. J. Millington, *The Wheat Industry in Australia*, 103.
Ceramics for the Archaeologist, A. O. Shepard, 268
Chevalley, I. C., *Theory of Lie Groups*, 324
Child Development, E. B. Hurlock, 269
Clagett, M., *Greek Sciences in Antiquity*, 101
Corn and Its Early Fathers, H. A. Wallace and W. L. Brown, 107

Die Flechtbinse (Scirpus lacustris L.), vol. XXI of *Die Binnengewässer*, K. Seidel, 266
Discovery of the Elements, M. E. Weeks, 325
Discussions on Child Development, Proceedings of the World Health Organization Study Group on the Psychological Development of the Child, vols. I and II, J. M. Tanner and B. Inhelder, Eds., 323
Diseases of the Endocrine Glands, L. J. Soffer, 45
Disposal of Sewage and Other Water-Borne Wastes, K. Imhoff, W. J. Müller, D. K. B. Thistlethwaite, 270

Earth beneath Us, The, H. H. Swinnerton, 161
Earth Satellites, P. Moore, 158

Earth, Sky and Sea, A. Piccard, 44
Earth We Live On, The, R. Moore, 215
Eckenfelder, W. W., Jr. *See* McCabe, Brother J., 214
Encyclopaedia of the Iron and Steel Industry, An, A. K. Osborne, compiler, 322
Evolution of Human Nature, The, C. J. Herrick, 156
Exploration of Mars, The, W. Ley and W. von Braun, 44

Fighting Cheyennes, The, G. B. Grinnell, 270
Flora, S. D., *Hailstorms of the United States*, 158
Freshwater Fishery Biology, K. F. Lagler, 265
Fun with Figures, J. A. H. Hunter, 106
Future of Arid Lands, The, G. F. White, Ed., 267

Galathea Deep Sea Expedition 1950–1952, The, A. F. Bruun, S. Greve, H. Mielche, R. Sparck, 322
Gartmann, H., *Man Unlimited*, 324
Great Chain of Life, The, J. W. Krutch, 321
Greek Science in Antiquity, M. Clagett, 101
Grigor'ev, N. I., *Surgical Treatment of Penetrating Wounds of the Heart, Pericardium and Mediastinum*, 47
Grinker, R. R., and H. MacG. Hughes, Eds., *Toward a Unified Theory of Human Behavior*, 104
Grinnell, G. B., *The Fighting Cheyennes*, 270

Hailstorms of the United States, S. D. Flora, 158
Hamacher, H. F. *See* Stevens, R., 48
Handbook of Biological Data, W. S. Spector, Ed., 105
Harlan, J. R., *Theory and Dynamics of Grassland Agriculture*, 160
Herrick, C. J., *The Evolution of Human Nature*, 156
Historical Background of Chemistry, The, H. M. Leicester, 157
How to Make and Use a Telescope, H. P. Wilkins and P. Moore, 50
Hughes, H. MacG. *See* Grinker, R. R., 104
Human Heredity Handbook, The, A. Scheinfeld, 46
Hunter, J. A. H., *Fun with Figures*, 106

Imhoff, K., W. J. Müller, D. K. B. Thistlethwaite, *Disposal of Sewage and Other Water-Borne Wastes*, 270
In Search of Adam, H. Wendt, 108
Individual Psychology of Alfred Adler, The, H. L. Ansbacher and R. R. Ansbacher, Eds., 271
Inhelder, B. *See* Tanner, J. M., 323
Integration, E. J. McShane, 324
Introduction to Microfossils, D. J. Jones, 106

Jay, K., *Calder Hall*, 160

Krutch, J. W., *The Great Chain of Life*, 321

Lagler, K. F., *Freshwater Fishery Biology*, 265
Leicester, H. M., *The Historical Background of Chemistry*, 157
Levitt, I. M., *A Space Traveler's Guide to Mars*, 214
Ley, W., and W. von Braun, *The Exploration of Mars*, 44
Life of Sir William Ramsay, A, M. W. Travers, 213
Lobeck, A. K., *Things Maps Don't Tell Us*, 159

Man Unlimited, H. Gartmann, 324
Manton, L., Ed., *Advances in Electronics and Electron Physics*, vol. VIII, 323
McCabe, Brother J., and W. W. Eckenfelder, Jr., Eds., *Biological Treatment of Sewage and Industrial Wastes*, vol. 1, *Aerobic Oxidation*, 214
McKelvey, S. D., *Botanical Exploration of the Trans-Mississippi West, 1790–1850*, 161
McShane, E. J., *Integration*, 324
Microscopium, M. Rooseboom, 269
Millington, A. J. *See* Callaghan, A. R., 103
Moore, P., *Earth Satellites*, 158; *See* also Wilkins, H. P., 50
Moore, R., *The Earth We Live On*, 215
Morris, C., *Varieties of Human Value*, 49
Müller, W. J. *See* Imhoff, K., 270

Neaverson, E., *Stratigraphical Palaeontology*, 45

Needham, J., *Science and Civilisation in China*, vol. 2, *History of Scientific Thought*, 213
Newman, J. R., *The World of Mathematics*, 217
Neyman, J., Ed., *Proceedings of the Third Berkeley Symposium on Mathematical Statistics and Probability*, vol. IV, *Contributions to Biology and Problems of Health*, 104; vol. V, *Contributions to Econometrics, Industrial Research and Psychometry*, 48

Old Stone Age, The, M. C. Burkitt, 216
On Freedom and Free Enterprise, M. Sennholz, Ed., 216
Opinions and Personality, M. B. Smith, 102
Osborne, A. K., compiler, *An Encyclopaedia of the Iron and Steel Industry*, 322

Piccard, A., *Earth, Sky and Sea*, 44
Proceedings of the Third Berkeley Symposium on Mathematical Statistics and Probability, vol. IV, *Contributions to Biology and Problems of Health*, J. Neyman, Ed., 104; vol. V, *Contributions to Econometrics, Industrial Research and Psychometry*, J. Neyman, Ed., 48
Psychology of Occupations, The, A. Roe, 47

Roe, A., *The Psychology of Occupations*, 47
Rooseboom, M., *Microscopium*, 269

Scheinfeld, A., *The Human Heredity Handbook*, 46
Science and Civilisation in China, vol. 2, *History of Scientific Thought*, J. Needham, 213
Scientific Sampler, A, R. Stevens, H. F. Hamacher, A. A. Smith, Eds., 48
Search beneath the Sea, The, J. L. B. Smith, 101
Seidel, K., *Die Flechtbinse (Scirpus lacustris L.)*, vol. XXI of *Die Binnengewässer*, 266
Sennholz, M., Ed., *On Freedom and Free Enterprise*, 216
Shapiro, H. L., *Aspects of Culture*, 321
Shepard, A. O., *Ceramics for the Archaeologist*, 268
Smith, A. A. *See* Stevens, R., 48
Smith, J. L. B., *The Search beneath the Sea*, 101
Smith, M. B., *Opinions and Personality*, 102
Soffer, L. J., *Diseases of the Endocrine Glands*, 45
Space Traveler's Guide to Mars, A, I. M. Levitt, 214
Spector, W. S., Ed., *Handbook of Biological Data*, 105
Stevens, R., H. F. Hamacher, A. A. Smith, Eds., *A Scientific Sampler*, 48
Stratigraphical Palaeontology, E. Neaverson, 45
Surgical Treatment of Penetrating Wounds of the Heart, Pericardium and Mediastinum, N. I. Grigor'ev, 47
Swinnerton, H. H., *The Earth beneath Us*, 161

Tanner, J. M., and B. Inhelder, Eds., *Discussions on Child Development, Proceedings of the World Health Organization Study Group on the Psychological Development of the Child*, vols. I and II, 323
Theory and Dynamics of Grassland Agriculture, J. R. Harlan, 160

Theory of Lie Groups, I. C. Chevalley, 324
Things Maps Don't Tell Us, A. K. Lobeck, 159
Thistlethwaite, D. K. B. *See* Imhoff, K., 270
Toward a Unified Theory of Human Behavior, R. R. Grinker and H. MacG. Hughes, Eds., 104
Travers, M. W., *A Life of Sir William Ramsay*, 213

Usinger, R. L., Ed., *Aquatic Insects of California, with Keys to North American Genera and California Species*, 108

Varieties of Human Value, C. Morris, 49

Wallace, H. A., and W. L. Brown, *Corn and Its Early Fathers*, 107
Watson, F. G., *Between the Planets*, 103
Weeks, M. E., *Discovery of the Elements*, 325
Wendt, H., *In Search of Adam*, 108
Wheat Industry in Australia, The, A. S. Callaghan and A. J. Millington, 103
White, G. F., Ed., *The Future of Arid Lands*, 267
Wilkins, H. P., and P. Moore, *How to Make and Use a Telescope*, 50
Wind and the Weather, The, J. Bolton, 324
World of Mathematics, The, J. R. Newman, 217
World Symposium on Applied Solar Energy, Proceedings, 320

Analytic Subject Index

AAAS, committees of, 201; council meeting of, 151; dedication of new building of, 24; meeting report of Pacific Division of, 53; new headquarters building of, 54; New York meeting of, 204; officers of, 151, 201; and regional consultants on mathematics and science teaching, 154; and report of Interim Committee on the Social Aspects of Science, 146; representatives to council of, 203; socio-psychological prize of, 264; E. L. Tatum named to editorial board of, 264; traveling library program of, 212
Absorption, and effect on modifying solar energy, 57
Adolescents, and attitude toward scientists, 135
Aging, effect of radiation on, 5
Agriculture, and rice culture in Spain, 66
Animal, genetics and breeding of, 183; nature of mental processes in, 309
Antarctic geophysics, and International Geophysical Year, 143
Argiope aurantia, 33
Astronomy, and origin of elements, 91; and solar energy, 55; and Southern Hemisphere observatory, 111
Atmosphere, and effects on extraterrestrial energy, 55; and International Geophysical Year, 144

Bache, A. D., and Coast Survey, 290
Bee, honey, behavior in, 313
Behavior, freedom and control in human, 189; history of study of animal, 309; of man as supreme being among earth organisms, 245
Bird, navigation in, 315; nest-building behavior of, 314; songs of, 316
Bituminous sand, as source of oil, 283
Blood, effect of radiation on, 5
Bone, strontium-90 in, 243
British Medical Research Council, and report on radiation hazards, 8

Canalization, proposed for Moselle River, 255
Cancer, and nuclear radiation, 4
Cartography, and history of nautical charting, 290
Cellulose, silverfish digestion of, 123
Charting, nautical, history of, 290
Chemical elements, theories on origin of, 84
Clouds, and influence on solar energy, 59
Coal, world production and consumption of, 223
Coast Survey, development of, 290
Colorado, oil shale in, 275
Colorado Dam, controversy on, 199
Cosmic rays, and International Geophysical Year, 143
Ctenolepisma lineata, physiology of digestion in, 123
Culture, and human population, 165; and man's place in living nature, 251

Darwinism, Huxley's defense of, 171; and effect on man's outlook on life, 245
Determinism, in human behavior, 189
Drosophila, in radiation studies, 7, 9

Earth satellite, and International Geophysical Year, 144
Ecology, overpopulation and human, 165
Education, and motivation of high-school students to science, 135; and need of humanities in secondary schools, 197
Elements. *See* Chemical elements
Embryology, T. H. Huxley's contribution to, 173
Energy, and political science, 34; production and consumption of, 12, 221; solar, 55, 226
Erratum, for "Formation of the elements," W. A. Fowler, 200; for "Studies on deep mass culture of algae in Israel," A. M. Mayer, A. Eisenberg, M. Evenari, 200
Evolution, human, 171; and man's preeminence in nature, 245; and political science, 34
Experimentation, role of statistics in, 26

Fallout, of radiostrontium, 5, 237
Fasciola hepatica, life-cycle of, 231
Fertility, and population problem, 166
Flukes, damage to livestock by internal parasitic, 229
France, and canalization of Moselle River, 255
Freud, and genius, 75
Fuel, production and consumption of, 221
Fusion as source of energy, 228

Gas, natural, world production and consumption of, 222
Genetics, and animal breeding, 183; and human heredity counselors, 199; and man's preeminence in nature, 245; and nuclear radiation, 6, 18; and political science, 40
Genius, nature of, 75
Geodetic Survey, history of development of, 290
Germany, and canalization of Moselle River, 255
Glaciology, and International Geophysical Year, 143
Gypsum, on Sacramento Plain, 302, 304

Haemonchus contortus, life-cycle of, 233
Hassler, F. R., and Coast Survey, 290
Honey bee, behavior of, 313
Human being, biologic effects of radiation on, 3, 18, 237; ecological problems in overpopulation of, 165; predetermination in behavior of, 189; and preeminence in living nature, 245
Humanities, in secondary schools, 197
Humidity, and parasites, 233
Huxley, T. H., 171, 196

Icing, tunnel for research on, 83
Insect, nutrition in, 123

Insemination, controversies arising from artificial, 41
Instinct, in animals, 311
Instrumentation, in astronomy, 116
Intelligence, and man's place in living nature, 249
International Astronomical Union, 114
International Geophysical Year, meteorology in, 141
Intuition, and genius, 76

Lake, bottomless, on Sacramento Plain, 33
Learning, in animals, 313
Limestone, on Sacramento Plain, 302
Livestock, effects of parasites on, 229

Malaria, and rice growing in Spain, 72
Mathematics, motivation of high-school students to, 135
Mendelism, principles of, 183
Metal, requirements for light, 227
Meteorology, in International Geophysical Year, 141
Mexico, sulfur mining in, 128
Milk, strontium-90 in, 242
Moselle River, canalization of, 255

National Academy of Sciences, and report on radiation hazards, 8, 18
Nautical charting, history of, 290
Nematodes, damage to livestock by internal parasitic, 229
New Mexico, sinkholes in, 302
Nitrogen utilization, in silverfish, 127
Nuclear energy, strontium-90 as by-product of, 237; uses of, 11, 224
Nuclear reactors, types of, 15, 21
Nuclear synthesis, mechanism of, 86

Observatory, international, in Southern Hemisphere, 111
Oceanography, and International Geophysical Year, 142
Oil, sources of, 275; world production and consumption of, 221
Oil shale, as source of oil, 223, 276
Orchid, rare species of, 236
Overpopulation, study of problems in human, 165
Ozone, absorption in atmosphere of, 57

Paper, as food for silverfish, 123
Parasitology, and economy of livestock production, 229
Pecos River, and bottomless lakes, 302
Philosophy, and science, 178
Phonics, and discrepancies in spelling and pronunciation, 198
Photogrammetry, development of aerial, 293
Physics, of upper atmosphere and IGY, 143
Plastics, as protection for growing plants, 226
Plutonium, civilian uses for, 14
Political science, applications of science to, 34
Population, and mutations, 9; problems in human, 165
Population genetics, principles of, 184
Protozoans, damage to livestock by, 229
Psychoanalysis, and genius, 82
Psychology, and animal behavior, 309; and freedom in human behavior, 189

Radcliffe Observatory, in South Africa, 122
Radiation, effects and uses of nuclear, 3, 6, 11, 17, 41; solar, 55
Radioactive materials, global distribution of, from fallout, 238
Ransom, B. H., studies of parasites by, 232
Religion, and science, 178
Research, importance of statistics in, 26
Rice, Spanish culture of, 66

Sacramento Plain, topography of, 302
Sandstone on Sacramento Plain, 302, 304
Science, motivation of high-school students to, 135; popularization of, 171; and society, 21, 146
Science teaching, and need for humanities, 197
Scientific manpower, and motivation of high-school students, 135
Scientific methods, role of statistics in, 26
Scientists, as seen by adolescents, 135
Sheep, parasitic diseases of, 229
Silverfish, physiology of digestion in, 123
Sinkholes, on Sacramento Plain, 302
Soil, strontium-90 in, 240
Solar energy, on clear and cloudy days, 55; as source of fuel, 224
Song, study of bird, 316
Southern Hemisphere, international observatory for, 111
Spain, rice culture in, 66
Spider, web construction of, 33
Stars, synthesis of elements in, 91
Statistics, in scientific research, 26
Strontium-90, global distribution of, 237
Sulfur, Mexican mining of, 128
Sun, energy from, 55
Supernovae, and origin of elements, 88
Systematics, T. H. Huxley's contribution to, 173

Tatum, E. L., 264
Telescopes, astronomical, 111
Thermonuclear reaction, need for research on, 20
Thorium, nuclear reactor use of, 20

United Kingdom, and economics of nuclear power, 15
Uranium, nuclear reactor use of, 17, 20

Water, as source of energy, 224
Water vapor, on clear and cloudy days, 57
Worms, damage to livestock by internal parasitic, 229

X-rays, as a radiation hazard, 5

SENSATIONAL OPTICAL BARGAINS

See the Stars, Moon, Planets Close Up!
3" "PALOMAR, JR." REFLECTING TELESCOPE

60 & 120 Power An Unusual Buy!

Assembled - Ready to Use!

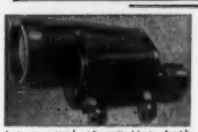
You'll see the Rings of Saturn, the fascinating planet Mars, huge craters on the Moon, Star Clusters, Moons of Jupiter in detail, Galaxies! Non - breakable aluminum covered tube. Equatorial mount with lock on both axes. Aluminized and overcoated 3" diameter high-speed f/10 ventilated mirror. Telescope comes equipped with a 60X eyepiece and a mounted Barlow Lens, giving you 60 and 120 power. An Optical Finder Telescope, always so essential, is also included. Sturdy, hardwood, portable tripod.

Free with scope: Valuable STAR CHART and 136 page book, "Discover the Stars".

Stock No. 85,050-X
$29.50 f.o.b. Barrington, N. J.
(Shipping wt. 10 lbs.)

Photographers!

Adapt your camera to this Scope for excellent Telephoto shots and fascinating photos of moon! Shown below is an actual photograph of the moon taken through our Astronomical Telescope by a 17 year-old student.



A "CLOSE-OUT" BARGAIN SPECIAL
7 x 50 MONOCULAR

This is fine quality, American made instrument—war surplus! Actually ⅓ of U. S. Govt. 7 x 50 Binocular. Used for general observation both day and night . . . to take fascinating telephoto shots. Brand new. $95 value. Due to Japanese competition we close these out at a bargain price. Directions and mounting Hints included. **Stock No. 50,003-X ..... $15.00 Pstpd.**

50-150-300 POWER MICROSCOPE
Low Price Yet Suitable for Classroom Use!
Only $14.95

3 Achromatic Objective Lenses on Revolving Turret!

Imported! The color-corrected, cemented achromatic lenses in the objectives give you far superior results to the single lenses found in the microscopes selling for $9.95! Results are worth the difference! Fine rack and pinion focusing.

Stock No. 70,008-X ..... $14.95 Pstpd.

MOUNTED 500 POWER OBJECTIVE

. . . Threaded for easy attachment on above microscope. Achromatic lenses for fine viewing. 3 mm focal length.

Stock #30,197-X ..... $5.00 Pstpd.

OPAQUE PROJECTOR—WAR SURPLUS

Made by Beseler for the Navy—Model OA. New complete with 300-watt, 115-volt bulb, projection lens and copy holders. About a $40.00 value. Use 8 to 15 feet from screen to get 2½ and 5 feet square pictures. Copy can be held front of projector and projector is furnished with a copy carrier for pictures you paste on 5 x 8 inch file cards and on 2½ x 3½" cards. Children love these. They can project their art work, comic books, school pictures, snapshots, colored pictures in full color, etc.

Stock No. 85,048-X (Shipping weight 14 lbs.)
$20.00 F.O.B. Barrington, N. J.

VARIABLE DENSITY GOGGLES—WAR SURPLUS

A O Polaroid. Headband to hold onto your head. Have soft rubber mounting in contact with your face. Small knob in front to rotate Polaroid filters to vary the density of light reaching your eyes. You can take apart and get four Polaroid glass mounted filters—1-3/16" diameter. Terrific value! Packed in small tin chest.

Stock No. 50,144-X ..... $2.50 postpaid

Fine, American-Made Instrument at Over 50% Saving
STEREO MICROSCOPE

Up to 3" Working Distance — Erect Image — Wide 3 Dimensional Field

Now, ready after years in development—this instrument answers the long standing need for a sturdy, efficient STEREO MICROSCOPE at low cost. Used in production—in research—in the lab, shop, factory, or at home: for inspections, examinations, counting, checking, assembling, dissecting—speeding up and improving quality control. 2 sets of objectives on rotating turret. Standard pair of wide field 10X Kellner Eyepieces give you 23 power and 40 power. Additional eyepieces available for greater or lesser magnification. A low reflection coated prism erecting system gives you an erect image—correct as to right and left—clear and sharp. Helical rack and pinion focusing. Precision, American-made! Storage chest included. 10-DAY TRIAL . . . complete satisfaction or your money back.

Order Stock No. 85,039-X (Shipping wt. approx. 11 lbs.)
Full price ..... $99.50 f.o.b. Barrington, N. J.
Send Check or M.O.

"FUN WITH OPTICS"

Tells How To Build Your Own Optical Instrument

Just out! 32 exciting pages! Easily understood, diagrammed instructions for building telephoto lenses, telescopes, microscopes, artist drawing projectors, slide viewers, close-up camera lenses, binoculars, riflescopes, etc. We can furnish the lenses, prisms, and parts you'll need. Right now order your copy of "FUN WITH OPTICS"—a terrific book—tells all about lenses and prisms, too.

Stock No. 9050-X .... 50¢ pstpd.

BUILD A SOLAR ENERGY FURNACE

A fascinating new field. You can build your own Solar Furnace for experimentation—many practical uses. It's easy—inexpensive. We furnish instruction sheet. This sun powered furnace will generate terrific heat—produces many unusual fusing effects. Sets paper aflame in seconds. Use our Fresnel Lens—14¾" diameter . . . f.l. 14".

Stock No. 70,130-X package of 1..$6.00 Postpaid
Stock No. 70,131-X package of 2..11.00 Postpaid
Stock No. 70,132-X package of 4..20.00 Postpaid

SIMPLE LENS KITS! Fun for adults! Fun for children! Kits include plainly written, illustrated booklet showing how you can build lots of optical items.

Stock No. 2-X—10 lenses $ 1.00 Postpaid
Stock No. 5-X—45 lenses $ 5.00 Postpaid
Stock No. 10-X—80 lenses $10.00 Postpaid

MEASURING POCKET MICROSCOPE - 50 POWER

No larger than an ordinary fountain pen, this handy pocket instrument is ideal for making direct reading measurements; for checking small parts and dimensions under powerful magnification. Speeds up quality control. Instrument contains a precision, glass etched reticle calibrated for measurements up to 1/10" by .001" divisions. Estimates to .0005" can easily be made. Chrome reflector at base of instrument reflects light on object examined or measured. Sturdy construction assures long, useful service.

Stock No. 30,225-X ..... $7.95 Postpaid

GET OUR GIANT FREE CATALOG-X

Over 1000 Optical Bargains
64 Fascinating Pages

Huge selection of lenses, prisms, war surplus optical instruments, parts and accessories. Telescopes, microscopes, binoculars. Hand spectroscopes, reticles, mirrors, Ronchi rulings, dozens of other hard-to-get optical items. America's No. 1 source of supply for Researchers, Lab. Technicians, Photographers, Hobbyists, Telescope Makers, etc. Ask for catalog X.

ORDER BY STOCK NUMBER . SEND CHECK OR MONEY ORDER . SATISFACTION GUARANTEED!

EDMUND SCIENTIFIC CO., BARRINGTON, NEW JERSEY

OXFORD books of exceptional interest

The Physics of Electrical Contacts

By F. L. JONES. A study of the fundamental processes involved in electrical contacts. Describes post-war research on the significant properties of materials used in contacts to give the reader a picture of all of the aspects of contact operation. (*Monographs on the Physics and Chemistry of Materials*) Illustrated. $5.60

Physical Properties of Crystals, Their Representation by Tensors and Matrices

By J. F. NYE. This systematic treatment of the tensor properties of crystals explains their common mathematical basis and the thermodynamical relations between them. *Text figures.* $8.00

Rectifying Semi-Conductor Contacts

By H. K. HENISCH. A specialized study of rectifying contacts between metals and semi-conductors. Introductory chapters are included for those not familiar with solid state physics. (*International Monographs on Physics*) 120 Text figures. $11.20

At all bookstores

OXFORD UNIVERSITY PRESS, INC.

114 Fifth Avenue, New York 11

(*Continued from page 325*)

Introduction to Bacterial Physiology. C. E. Clifton. McGraw-Hill, New York, 1957. 414 pp. $8.50.

Research Project for the Study and Treatment of Persons Convicted of Crimes Involving Sexual Aberrations. Final Report. June 1952 to June 1955. Bernard C. Glueck, Jr., Director. University of Minnesota Medical School, Minneapolis, 1956. 401 pp.

Philosophy of Science. The link between science and philosophy. Philipp Frank. Prentice-Hall, Englewood Cliffs, N.J., 1957. 394 pp. $7.65.

Chemical Phase Theory. A comprehensive treatise on the deduction, the applications and the limitations of the phase rule. J. Zernike. Kluwer's, Deventer, Netherlands, 1955. 493 pp. Fl. 70.

Heterocyclic Compounds. vol. 6, ***Six-Membered Heterocycles Containing Two Hetero Atoms and Their Benzo Derivatives.*** Robert C. Elderfield, Ed. Wiley, New York; Chapman & Hall, London, 1957. 753 pp. $25.

The Chemical Basis of Heredity. a Symposium. Sponsored by The McCollum-Pratt Institute of Johns Hopkins University with support from Atomic Energy Commission. William D. McElroy and Bentley Glass, Eds. Johns Hopkins University Press, Baltimore, 1957. 848 pp. $12.50.

Relaxation Spectrometry. E. G. Richardson. North-Holland, Amsterdam; Interscience, New York, 1957. 140 pp. $5.75.

Tokugawa Religion. The values of pre-industrial Japan. Robert N. Bellah. Free Press, Glencoe, Ill., 1957. 249 pp. $5.

Cenozoic Foraminifera of Micronesia. Memoir 66. Shoshiro Hanzawa. Geological Society of America, New York, 1957. 163 pp.

Semiconductor Surface Physics. R. H. Kingston, Ed. University of Pennsylvania Press, Philadelphia, 1957. 413 pp. $8.

Flora of Southeastern Washington and Adjacent Idaho. Harold St. John. Students Book Corp., Pullman, Wash., rev. ed., 1956. 561 pp.

Mechanical Engineering Laboratory, Instrumentation and Its Application. Jesse B. Doolittle. McGraw-Hill, New York, 1957. 396 pp. $6.50.

The Harvey Lectures. Delivered under the auspices of the Harvey Society of New York, 1955–1956. Series LI. Academic Press, New York, 1957. 298 pp. $7.50.

Properties of Petroleum Reservoir Fluids. Emil J. Burcik. Wiley, New York; Chapman & Hall, London, 1957. 190 pp. $7.50.

American Families. Paul C. Glick. 240 pp. $6. ***American Housing and Its Use.*** The demand for shelter space. Louis Winnick and Ned Shilling. 143 pp. $5.50. Wiley, New York; Chapman & Hall, London, 1957. (For the Social Science Research Council in cooperation with the U.S. Department of Commerce, Bureau of the Census).

TO AUTHORS
seeking a publisher

Learn how we can publish, promote and distribute your book on a professional, dignified basis. All subjects considered. Scholarly and scientific works a specialty. Many successes, one a best seller. Write for booklet SM—it's free.

VANTAGE PRESS, Inc. • 120 W. 31 St., N.Y. 1
In Calif.: 6253 Hollywood Blvd., Hollywood 28
In Wash., D.C.: 1010 Vermont Ave., NW

The First One Hundred and Fifty Years, a History of John Wiley and Sons, Incorporated, 1807–1957. Wiley, New York, 1957. 245 pp. $7.50.

Introduction to Physiological and Pathological Chemistry. L. Earle Arnow and Marie C. D'Andrea. Mosby, St. Louis, ed. 5, 1957. 529 pp. $4.25.

Operation Deepfreeze. George J. Dufek. Harcourt, Brace, New York, 1957. 243 pp. $5.

Dictionary of Microbiology. Morris B. Jacobs, Maurice J. Gerstein, William G. Walter. Van Nostrand, Princeton, N.J., 1957. 276 pp. $6.75.

The Reefs of Taprobane. Underwater adventures around Ceylon. Arthur C. Clarke. Harper, New York, 1956–57. 205 pp. $5.

The Oxidation and Weathering of Meteorites. Publications in Meteoritics, No. 3. John D. Buddhue. University of New Mexico Press, Albuquerque, 1957. 161 pp. Paper, $1.75.

The Prospects of Nuclear Power and Technology. Gerald Wendt. Van Nostrand, Princeton, N.J., 1957. 348 pp. $6.

Battle for the Mind. A physiology of conversion and brain-washing. William Sargant. Doubleday, Garden City, N.Y., 1957. 263 pp.

Outside Readings in Psychology. Eugene L. Hartley and Ruth E. Hartley. Crowell, New York, ed. 2, 1957. 499 pp. $2.50.

XIV International Congress of Zoology, Proceedings. Copenhagen, 5–12 August 1953. Danish Science Press, Copenhagen, 1956. 567 pp. Paper, Kr. 100.

College Geometry. Leslie H. Miller. Appleton-Century-Crofts, New York, 1957. 201 pp. $4.50.

Handbook of Solvents. vol. 1, ***Pure Hydrocarbons.*** Ibert Mellan. Reinhold, New York; Chapman & Hall, London, 1957. 259 pp. $6.50.

The Economic Factors in the Growth of Russia. An economic-historical analysis. Nicholas L. Fr.-Chirovsky. Philosophical Library, New York, 1957. 178 pp. $3.75.

Report of the Conference on Recent Developments in Cloud-Chamber and Associated Techniques. Comprising collected papers of the conference held under the joint auspices of the Physical Society of London and University College, London, in March 1955. N. Morris and M. J. B. Duff, Eds. University College, London, 1956 (order from Secretary, Physics Department, University College, London). 227 pp. 30s.

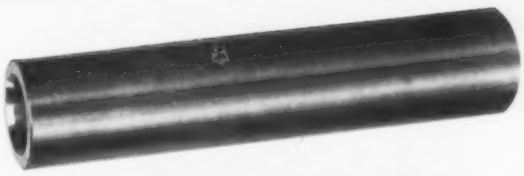
Chemical Engineering Reports. How to search the literature and prepare a report. Kenneth A. Kobe. Interscience, New York, ed. 4, 1957. 175 pp. $3.

Vitamin B_{12} and Intrinsic Factor. H. C. Heinrich, Ed. Enke, Stuttgart, Germany, 1957. 576 pp.

Handbuch der Physik. vol. XX, *Electrical Conductivity II.* S. Flügge, Ed. Springer, Berlin, 1957. 491 pp. DM. 112.

Molecular Structure and Functional Activity of Nerve Cells. A symposium organized by the American Institute of Biological Sciences and sponsored by the Office of Naval Research. Held in Washington, D.C., 3–4 June 1955. Publ. No. 1. Robert G. Grenfell and L. J. Mullins. American Institute of Biological Sciences, Washington, 1956. 169 pp. $4.75.

Vapor Phase Chromatography. Proceedings of the symposium sponsored by the Hydrocarbon Research Group of the Institute of Petroleum held at the Institution of Electrical Engineers, London, on 30 May–1 June 1956. D. H. Desty, Ed.; assisted by C. L. A. Harbourn. Academic Press, New York; Butterworths, London, 1957. 436 pp. $12.



KENNAMETAL'S
94,000,000 YME puts the squeeze on "cylinder breathing"

- prevents leakage around pistons
- stands up under extreme abrasive and corrosive conditions
- reduces compressor downtime needed for replacements or repairs

In making polyethylene, gases are compressed at pressures as high as 35,000 psi. Under such pressures, cylinder liners of conventional materials deform and permit gas to leak around the pistons. This "cylinder breathing" must be held within defined limits.

One compressor manufacturer solved this problem with cylinder liners of Kennametal.* This unique metal with YME of 94,000,000 psi, three times that of the hardest steel, and its exceptional compressive strength, not only confined gas leakage within tolerable limits but out-lasted any other metal due to its exceptional resistance to wear.

The high YME of Kennametal is being applied in many ways to improve products, processes or productive capacities. In addition to pump and compressor liners, it is used in spindles for precision instruments; integrator discs; shafts; grippers; rams; grooving blades and similar applications.

Other unique characteristics of Kennametal compositions, including high resistance to corrosion, heat, impact and cavitation are solving "metal problems" in the chemical industry in such parts as balls, seats, bushings, sleeves, valves, cones and similar components. Platinum bonded compositions are available for use where a combination of severe corrosion and abrasion is encountered.

Why not investigate Kennametal? A Kennametal carbide engineer will gladly discuss your problem with you. Or write for booklet B-111A, "Characteristics of Kennametal." KENNAMETAL INC., Dept. MS, Latrobe, Pennsylvania.

*Trademark

C-3028B

INDUSTRY AND KENNAMETAL
...Partners in Progress

TINY BABE and MIDGET HOISTS

Easily Lifts Up To 2000 Lbs.

This amazing block and tackle is portable . . . weighs only 13 ounces. Fits in your pocket, in glove compartment of your car. Carry it anywhere. A one hand operation that is easy to use. Powerful, lifts up to 2000 pounds.

LITTLE GIANTS THAT WEIGH LESS THAN A POUND

Because of their great strength and small sizes these hoists have a multitude of uses: in your car for emergencies; in your home and work shop; on the farm, stretching fences; on vacation; sportsmen, loading deer and elk; or for loading boats or other heavy articles. Handy around industrial plants, too. The finest engineered hoists made anywhere. Best grade aluminum, with steel axles. Pre-lubricated for life. Hoists have two lifting slings, one at the top and one at the bottom, with heavy welded steel rings. Slings can be doubled for added strength. Nylon cord tests 550 lbs. per strand. These Tiny Hoists will lift from 1000 to 2000 pounds. MIDGET BABE comes with 70 ft. nylon cord. 5 to 1 ratio—1000 pound test. Weight: 13 ounces. Price $9.95. TINY BABE has 100 ft. nylon cord, 7 to 1 ratio—2000 pound test. Weight: 15 ounces. Price: $12.95. Furnished with orange colored carrying bag. You can put it in your pocket. These hoists are unconditionally guaranteed for one year. Sold with a money back guarantee . . . .

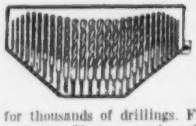
MIDGET BABE $9.95 **TINY BABE $12.95**

7 Power ILLUMINATED LOUPE

A must for every handyman, hobbyist, student. Imagine, a precision - built 7 power magnifier with built - in light so every detail stands out clear and sharp, regardless of outside illumination. Coated lens. Battery model. An opening in the housing permits use with other instruments. Lens diameter 1-3/16". Supplied with linen tester plate for thread counting, which fits into the bottom of the housing.

An absolutely amazing value. Also available 5x50—$4.95. Worth $9.95 (batteries not included) NOW only **$4.95 ppd.**

29-Pc. Chrome Vanadium Drill Set



Specially made for speed drilling. In sturdy plastic tool roll. Finest alloy steel drills hardened and precision ground to the sharpest, longest lasting cutting edge obtainable; will easily and cleanly bite through hardwoods, plastics, aluminum, iron and the toughest steels. Unconditionally guaranteed for thousands of drillings. Full jobber length. Sizes by 64th from 1/16" to 1/2". There are only a limited quantity of sets available at this low price, so hurry! **$6.49 ppd.**

Also available with Turned Down Shanks to fit all 1/4" drills. In individual pocket roll. **$8.95 ppd.**

60 Pc. Set Wire Gauge CHROME VANADIUM DRILLS

Top quality high test Chrome Vanadium Drills designed for speed drilling through toughest steels, woods, plastic, iron and aluminum. Precision ground, long-lasting cutting edges. Guaranteed to give years of satisfaction. A full 60 pc. set nos. 1 through 60.

A $14.95 value—NOW ONLY $5.40

Same set above available with Huot Index container—Only $6.65
All above drill sets plus 35¢ pp. & hdlg.

Also available 61-80 set of high quality drills, in plastic kit with marked pocket for each drill $2.50

Min. order $1. Send Check or M.O. C.O.D. plus fee. Money Back Guarantee.

SCOTT-MITCHELL HOUSE, INC.

Dept. 7106, 611 Broadway, New York 12, N. Y.

Meetings

July

1–3. Reproduction and Infertility, 3rd symp., Fort Collins, Colo. (F. X. Gassner, Colorado State Univ., Fort Collins.)

1–6. Brazilian Soc. for the Advancement of Science, 9th annual, Rio de Janeiro, Brazil. (Sociedade Brasileira Para o Progresso da Ciencia, Caixa Postal 2926, São Paulo, Brazil.

1–6. Industrial Medicine, 12th internatl. cong., Helsinki, Finland. (L. Noro, Medical Director, Inst. of Occupational Health, Huapalahdenkatu 1, T8818, Helsinki.)

2–4. Neurological Basis of Behavior, Ciba Foundation Symp. (by invitation only), London, England. (C. E. W. Wolstenholme, Ciba Foundation, 41 Portland Pl., London, W.1.)

2–6. Physical Problems of Color Television, internatl. symp. of IUPAP, Paris, France. (Secretary, Colloque International sur les Problèmes de la Télévision en Couleurs, Conservatoire National des Arts et Metiers, 292, rue Saint-Martin, Paris 3e.)

3–6. Current Problems in Crystal Physics, conf., IUPAP and NSF, Cambridge, Mass. (J. S. Slater, Massachusetts Inst. of Technology, Cambridge 39.)

8–10. Astrophysical Symp., 8th internatl., Liége, Belgium. (P. Swings, Institut d'Astrophysique, Université de Liége, Liége.)

8–10. Endocrine Aspect of Breast Cancer, internatl. conf., Glasgow, Scotland. (A. P. M. Forrest, Dept. of Surgery, Western Infirmary, Glasgow, W.1.)

8–12. Inter-American Cong. of Philosophy, 5th, Washington, D.C. (R. M. Chisholm, Brown Univ., Providence, R.I.)

8–12. Poliomyelitis Conf., 4th internatl., Geneva, Switzerland. (Secretariat, 4th International Poliomyelitis Conference, Hotel du Rhone, Geneva.)

9–11. Biological Symp., 8th annual, Univ. of Michigan, Ann Arbor. (B. L. Baker, Dept. of Anatomy, Univ. of Michigan, Ann Arbor.)

9–13. European Molecular Spectroscopy Conf., Freiburg, Breisgau, Germany. (R. Mecke, Dept. of Physical Chemistry, Univ. of Freiburg, Breisgau.)

9–13. International Cong. for the Study of Social Insects, Paris, France. (G. Richard, International Union for the Study of Social Insects, Faculty of Sciences, University of Rennes, Rennes, France.)

10–12. Thermodynamic and Transport Properties of Fluids, conf., IUPAC, London, England. (Institution of Mechanical Engineers, 1, Birdcage Walk, Westminster, London, S.W.1.)

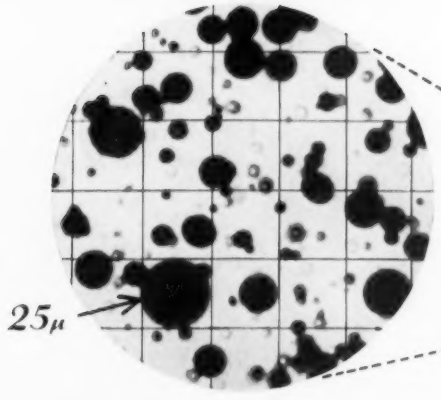
10–17. International Union of Crystallography, 4th genl. assembly, Montreal, Canada. (G. A. Jeffrey, Chemistry Dept., Univ. of Pittsburgh, Pittsburgh 13, Pa.)

14–19. International Assoc. of Gerontology, Merano, Italy. (A. I. Lansing, Dept. of Anatomy, Univ. of Pittsburgh, Pittsburgh 13, Pa.)

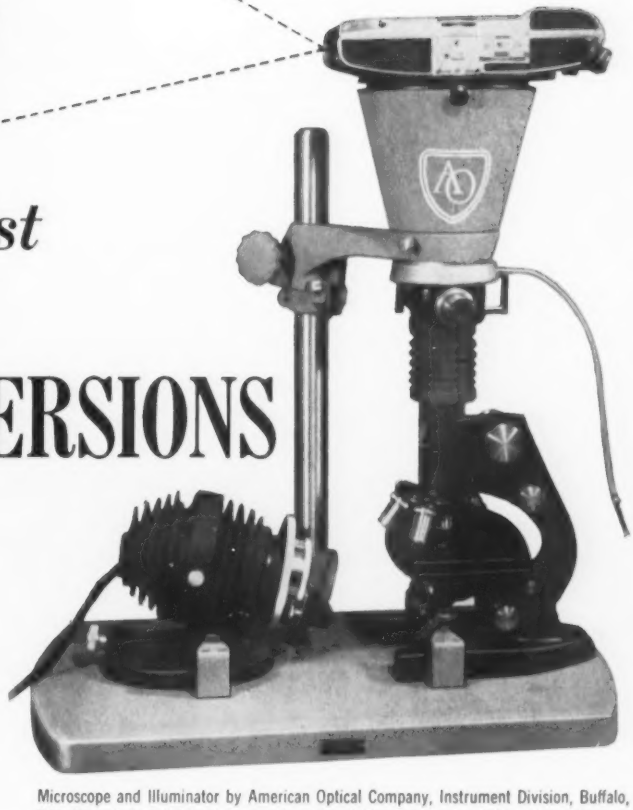
14–20. Clinical Pathology, 4th internatl. cong., Brussels, Belgium. (M. Welsch, Service de Bacteriologie et de Parasitologie, Université de Liége, Blvd. de la Constitution, Liége, Belgium.)

15–19. Institute on College Administration, annual, Ann Arbor, Mich. (A. D. Henderson, 2442 U.E.S., Univ. of Michigan, Ann Arbor.)

16–19. American Malacological Union, annual, New Haven, Conn. (Miss M. C. Teskey, P.O. Box 238, Marinette, Wis.)



Here's the *latest* on Lithium METAL DISPERSIONS



Microscope and Illuminator by American Optical Company, Instrument Division, Buffalo, New York. Polaroid® Land Camera by Polaroid Corporation, Cambridge, Massachusetts.

Got a catalyst problem?

Interest sparked by the discovery that lithium metal dispersions make unique polymerization catalysts (the polymerization of isoprene to a "natural" rubber) indicates a heretofore unexploited instrument of research.

Consequently, Lithium Corporation is now making available experimental quantities of dispersions of this highly reactive metal. These dispersions may be purchased in either mineral oil or a mineral oil-petrolatum combination as the dispersing medium. Dispersions in other media are available as special items. The "package" is obtainable in five sizes from 25 grams to 1 pound. Over 90% of the lithium metal particles have a diameter less than 25 microns.

Specifications, information for preparing the dispersions including handling instructions, prices and product data on lithium metal may be obtained by submitting a request on company or institutional stationery.

... trends ahead in industrial applications for lithium

LITHIUM CORPORATION OF AMERICA, INC.
2698 RAND TOWER, MINNEAPOLIS 2, MINN.

PROCESSORS OF LITHIUM METAL • METAL DISPERSIONS
METAL DERIVATIVES: Amide • Hydride
SALTS: Bromide • Carbonate • Chloride • Hydroxide • Nitrate
SPECIAL COMPOUNDS: Aluminate • Borate • Borosilicate • Cobaltite • Manganite
Molybdate • Silicate • Titanate • Zirconate • Zirconium Silicate

BRANCH SALES OFFICES: New York • Chicago • Bessemer City, N. C.
MINES: Keystone, Custer, Hill City, South Dakota • Bessemer City, N. C.
Cat Lake, Manitoba • Amos Area, Quebec
PLANTS: St. Louis Park, Minnesota • Bessemer City, N. C.
RESEARCH LABORATORY: St. Louis Park, Minnesota

In systems engineering work, it is necessary to bring together a team that includes scientists and engineers of a wide range of technical specialties. In major weapons-systems projects, such teams will include hundreds of scientists and engineers.

But the assembly of a large group of scientists and engineers, no matter how capable they may be individually, does not of itself ensure good systems-engineering performance. The caliber of the project management has a major effect upon its technical accomplishment. It is not easy to coordinate the activities of large numbers of scientists and engineers so as not to stifle their creativeness on the one hand, nor to permit the various development sub-efforts to head toward mutually incompatible objectives on the other.

Of primary importance for good systems management is the philosophy underlying the selection of the supervisory personnel. The head of a technical activity should, first of all, be a competent scientist or engineer. A common mistake – nearly always fatal in systems work – is to fill such positions by non-technical men who have been trained only in management techniques. In the highly complex activities of major systems work, what is required is *technical management*, and of the two words, the word *technical* must never be overlooked.

In the selection of scientists and engineers for technical management, it is essential that the men chosen be broad in their training and approach. Each principal department head, for example, must have a good basic understanding of the technical facts of life of the other departments. When these people get together they need to speak a common language and understand each other's fields, so that proper decisions can be made on the many interrelated problems that come up. The higher the organizational responsibility of a technical manager, the more important this factor becomes.

The Ramo-Wooldridge Corporation is engaged almost entirely in systems work. Because of this, the company has assigned to scientists and engineers more dominant roles in the management and control of the business than is customary or necessary in most industrial organizations.

Scientists and engineers who are experienced in systems engineering work, or who have specialized in certain technical fields but have a broad interest in the interactions between their own specialties and other fields, are invited to explore openings at The Ramo-Wooldridge Corporation in:

Guided Missile Research and Development
Aerodynamics and Propulsion Systems
Communications Systems
Automation and Data Processing
Digital Computers and Control Systems
Airborne Electronic and Control Systems
Basic Electronic and Aeronautical Research

The Ramo-Wooldridge Corporation

5730 ARBOR VITAE ST. • LOS ANGELES 45, CALIF.